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WITH CONTENTS

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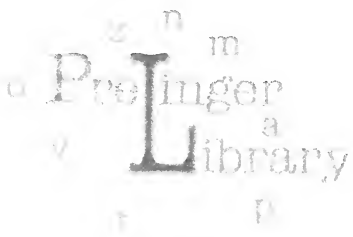

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UNITED STATES DEPARTMENT OF AGRICULTURE
WASHINGTON, D. C.

BIOLOGY OF THE PRIMARY SCREW WORM FLY, COCHLIOMYIA AMERICANA, AND A COMPARISON OF ITS STAGES WITH THOSE OF C. MACELLARIA

By E. W. LAAKE, *senior entomologist*, EMORY C. CUSHING, *senior entomologist*, and H. E. PARISH, *assistant entomologist*, *Division of Insects Affecting Man and Animals, Bureau of Entomology and Plant Quarantine*

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INTRODUCTION

Screw worms have long been known to inflict serious injury to man and animals in the subtropical and tropical regions of North America and South America. The recent discovery [1] that at least two species of these flies have been confused heretofore under the name *Cochliomyia macellaria* Fab. raises a doubt as to which species was considered in the earlier published information relating to this subject. Because of the similarity of these two flies in their outward appearance, the fact that data concerning them are now questionable, and the ever-increasing importance of their activities, a newer knowledge of the economic status of each must be obtained.

While much remains to be determined concerning both species, the data here presented give the results of studies conducted by the Bureau of Entomology and Plant Quarantine to date on the biology and habits of *Cochliomyia americana* C. and P.[2]

[1] CUSHING, E. C., and PATTON, W. S. STUDIES ON THE HIGHER DIPTERA OF MEDICAL AND VETERINARY IMPORTANCE. COCHLIOMYIA AMERICANA SP. NOV., THE SCREW-WORM FLY OF THE NEW WORLD. Ann. Trop. Med. and Parasitol. 27: 539–551, illus. 1933.

[2] While it is possible that the primary screw worm fly may have been described by earlier workers under such names as *hominivorax, anthropophaga, fulvobarbata, infesta,* and others, an authentic name for this species can be assigned only after an examination of all type specimens has been made. For the present, it is deemed more appropriate to use the name *C. americana* to designate the primary screw worm fly of the New World, even though an older name may be adopted later.

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ECONOMIC IMPORTANCE

Apparently all warm-blooded animals are susceptible to infestation. Any type of wound, the navels of young animals, and the natural openings of the body, such as nostrils, mouth, eyes, ears, vagina, and anus, may become infested with the larvae of *Cochliomyia americana*. Infestation of the natural openings is usually the result of an injured, diseased, or unclean condition.

The evidence indicates that this fly is a primary, obligatory parasite and that it initiates the vast majority of cases of external myiasis, commonly called screw worm infestations, in man and animals in the United States and probably in the entire neotropical region. Not only is it important as a primary invader of wounds, but it will also continue to infest necrotic lesions. It is known to be the specific cause of a large number of cases of nasopharyngeal myiasis in man in the New World Tropics. Only one case of this type has been observed among domestic animals, a sheep on a ranch in southwestern Texas.

Table 1 gives the number and species of flies reared from each of 114 cases of myiasis occurring in domestic animals on one ranch in southwestern Texas during the year 1934. These animals became naturally infested on the range and were brought into the corrals for treatment. Most of the cases were found before the infestations became extensive and before the maggots first infesting the wound had matured. None of the cases recorded was a reinfestation; that is, the wound from which the maggots were taken had not been previously treated for an infestation.

TABLE 1.—*Number and species of flies reared from 114 cases of myiasis in all classes of range livestock on one ranch, Sonora, Tex., April to July 1934*

Species of flies bred from infested wounds	Cases	Percentage of total cases	Flies reared from cases	Percentage of each species in cases				
				Cochliomyia americana C. and P.	*Cochliomyia macellaria* Fab.	*Phormia regina* Meig.	*Sarcophaga plinthopyga* Wied.	*Lucilia sericata* Meig.
	Number	*Percent*	*Number*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
C. americana	91	79.8	1,430	100	0	0	0	0
C. americana and *C. macellaria*	3	2.6	110	90.9	9.1	0	0	0
C. americana and *S. plinthopyga*	4	3.5	169	34.3	0	0	65.7	0
C. americana and *P. regina*	1	.9	25	88.0	0	12.0	0	0
C. americana, *C. macellaria*, and *P. regina*	1	.9	7	42.9	14.2	42.9	0	0
C. americana, *P. regina*, and *S. plinthopyga*	2	1.8	126	56.3	0	7.1	36.6	0
C. americana, *C. macellaria*, *P. regina*, *S. plinthopyga*, and *L. sericata*	1	.9	788	16.8	66.1	15.8	.8	.5
C. macellaria	2	1.8	34	0	100	0	0	0
C. macellaria and *P. regina*	3	2.6	53	0	18.9	81.1	0	0
C. macellaria and *S. plinthopyga*	1	.9	55	0	47.3	0	52.7	0
C. macellaria, *S. plinthopyga*, and *L. sericata*	1	.9	110	0	69.1	0	17.3	13.6
P. regina	1	.9	11	0	0	100	0	0
S. plinthopyga	3	2.6	39	0	0	0	100	0

The history of the 11 cases from which no *Cochliomyia americana* were reared shows that in 2 cases the infestation occurred in a suppurative lesion containing pathogenic bacteria and in 3 cases it occurred in the soiled wool of sheep without involvement of the tissues.

Cochliomyia americana has been obtained in pure cultures from many other cases occurring in other parts of Texas and in Louisiana, Mississippi, Alabama, Georgia, Florida, and South Carolina, and from a few cases in Iowa and Indiana.

DISTRIBUTION

Normally the fly is confined to the tropical and subtropical sections of the United States and the countries to the south; it has, however, caused trouble in the Northern States. A list is given below of places from which authentic records of its occurrence have been obtained, although it is quite probable that the fly is present in several other States and countries.

North America: Texas, Louisiana, Mississippi, Alabama, Florida, Georgia, South Carolina, Missouri, Iowa, Illinois, Indiana, Oklahoma, California, Arizona, New Mexico, Kentucky, Tennessee, and Kansas.

West Indies and Central America: Trinidad, St. Lucia, Dominican Republic, Puerto Rico, and Panama.

South America: Colombia, British Guiana, French Guiana, Brazil, Uruguay, Argentina, and Venezuela.

This fly is not a recent invader of the United States. The earliest authentic record known at present of the occurrence of screw worm cases caused by *Cochliomyia americana* in this country dates back to 1882.

SEASONAL ACTIVITY OF THE FLY

In the United States *Cochliomyia americana* usually begins its activities late in the spring or early in the summer, the exact time varying with the temperature of the season in a particular locality. The first authentic case in Georgia in 1934 occurred on May 15. During the same season at Menard and Sonora, Tex., the first cases were observed on April 16 and 19, respectively. Infestations occurred in Florida and southern Georgia during January and February of 1935. W. V. King of this Bureau recorded 17 infestations of animals in northern and central Florida during the winter of 1934–35, 15 of which occurred from January 8 to 19, inclusive, 1 on February 14, and 1 on February 22. The minimum temperature recorded in northern Florida during December 1934 was 16° F.

In Texas, R. A. Roberts reared *Cochliomyia americana* from an infested animal at Uvalde on January 19, 1935, and at Raymondville W. R. Hutchins collected larvae of this species from a wound on February 13, 1935.

DESCRIPTION OF STAGES, LIFE HISTORY, AND HABITS

Like most of the species of blowflies, *Cochliomyia americana* has five developmental stages in its life cycle.

THE EGG

DESCRIPTION

The egg of *Cochliomyia americana* (fig. 1) is approximately 1.04 mm in length and 0.22 mm in width (average of 10). It is glistening white with a very slight tinge of cream color, rounded at the

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posterior and somewhat flattened at the micropylar end, and with a dorsal ridge or seam extending from the micropylar end almost to the opposite pole. As incubation proceeds the egg assumes a grayish color due to the development of numerous spines on the body of the encased larva. It is easily distinguished from the egg of the closely related species *C. macellaria*, having considerably less cream color. The dorsal seam divides at the anterior end and extends downward around the micropyle in a broad band, giving the appearance of a circular cap. In *C. macellaria* the extension of the dorsal seam around the micropyle forms a much narrower band and the cap therefore appears considerably smaller. Under high magnification the outer covering of an egg of *C. americana* has a reticulated or lacework appearance.

HATCHING

The process of hatching has been observed under the microscope in several instances. The eggs were placed on moist blotting paper in a glass dish and this was mounted on the microscope stage. The observations on the process of hatching described here were made in a room temperature that ranged from 101° F. at the time the eggs were laid to 90° at the moment the first larvae emerged. The total incubation period in this particular instance was 9 hours and 34 minutes. Under these conditions the first movements of the larvae could be seen through the eggshell 8 hours after the eggs were laid. It appears that the first-stage larvae are well developed some time before they emerge from the egg, approximately the last 1½ to 2 hours of the incubation period being devoted first to opening a hole in the micropylar end and then to splitting the egg shell along the dorsal seam. During the process of emerging the young larva opens a small slit along the dorsal seam at the anterior end of the egg. This slit is gradually increased in length by the activity of the encased larva, until at the time of emergence the eggshell is opened for two-thirds or more of its length. It frequently happens that the part of the seam which extends around the micropyle is split completely around and the entire micropylar end is pushed outward as a circular flap.

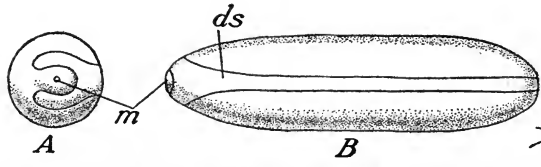

FIGURE 1.—Egg of *Cochliomyia americana*: *A*, End view; *B*, dorsal view; × 50; *m*, micropyle; *ds*, dorsal seam.

INCUBATION

The incubation period varies with the temperature and relative humidity. Under natural conditions (i. e., eggs on wounds in animals) the duration of the period ranged from 11 to 21.5 hours. Roy Melvin, at Dallas, Tex., has determined that under controlled laboratory conditions of 100 percent relative humidity the incubation period ranged from 9.2 hours at 99° F. to 13.9 hours at 84°, and that no hatching took place at 59°. He has shown also that the duration of the incubation period is almost twice that required for *Cochliomyia macellaria* under similar conditions.

W. E. Dove of this Bureau, working at the Savannah, Ga., laboratory, observed one instance in which eggs laid on a moist lanced abscess on a guinea pig had an incubation period as short as 6 hours.

EGG MASS

Eggs are usually deposited in regular, oval, shinglelike masses of from 10 to 393 each, on dry surfaces at the edge of both fresh and necrotic wounds. They may be laid also on dried blood clots, scabs, and exudate, even where a break in the skin is not apparent. In one case the eggs were deposited on the moist suppurating surface of a wound. In almost all cases the masses are glued tightly to the surface on which they are laid and the eggs are firmly cemented together. The egg masses are easily distinguished from those of *Cochliomyia macellaria*, which are laid in irregular groups in the hair or wool of the animal and only loosely or not at all attached to the surface of the skin, and the eggs are also less firmly cemented together than are those of *C. americana*.

THE LARVA OF COCHLIOMYIA AMERICANA AND THAT OF THE ASSOCIATED C. MACELLARIA[3]

There are the usual three larval instars in the development of *Cochliomyia americana* and *C. macellaria*. The first-instar larvae may be distinguished from those of the second and third instars by the absence of anterior spiracles, by the general structure of the cephalopharyngeal sclerites, and by the absence of a ring or peritreme which partly surrounds the spiracular slits in the second and third instars (figs. 2, 3, and 9). The second-instar larvae may be distinguished from those of the third instar by the structure of the cephalopharyngeal sclerites (fig. 6) and by the posterior spiracles; in the second instar there are two slits per spiracle, whereas in the third instar there are three.

The descriptions and figures here given are based on examinations of mounted and unmounted specimens.

The larvae of *C. americana* examined for the descriptions were collected at Sonora, Tex., and Ames, Iowa. In addition, third-instar larvae collected from wounds of animals from several points in the southern part of the United States and in Iowa were examined. The characteristics of the larvae as described appear to be the same in specimens examined from the various regions.

The larvae of *C. macellaria* were reared specimens collected at Ames, Iowa, and Dallas, Tex., and the characteristics checked with larvae obtained from one case of myiasis in Florida. As in *C. americana*, the characteristics appear to be the same in the specimens from the various localities.

COCHLIOMYIA AMERICANA CUSHING AND PATTON

FIRST INSTAR

Larva elongate, more or less cylindrical in shape, with 12 apparent segments, tapering anteriorly from the sixth segment; the last three segments slightly tapering posteriorly (fig. 2). Length and width

[3] By E. F. Knipling, assistant entomologist, Bureau of Entomology and Plant Quarantine.

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at time of hatching 1.2 and 0.23 mm, respectively; fully developed first-instar larvae average 3.6 mm in length and 0.57 mm in width at the widest point.

Armed with large, dark, single-point, recurved spines, arranged in more or less irregular rows near the margin of the segments. Spines in anterior rows largest, the larger spines measuring approximately 20μ in length, as compared to 6μ, the length of similar spines of *Cochliomyia macellaria*.

Anterior margin of segments 2 to 9 completely encircled with a band of spines; on segment 10 the band interrupted for a short space on dorsum. On segment 11 the spines are absent on the dorsum and on the sides are reduced to two or three rows of small, more lightly pigmented spines. On segment 12 they are confined to the ventral and ventrolateral surfaces. On the ventral surface of segments 6 to 12 the band of spines is wider and transversely divided by a narrowed spineless area. Posterior margin of the segments devoid of spines except two or three rows of small spines on the ventral surfaces of segments 5 to 12. On segments 5 to 10, on the sides of each segment, is a small swollen area, the lateral fusiform area, which is provided with a group of spines.

The twelfth or last apparent segment is depressed behind, and in the depression nearer the upper end are located the two posterior spiracles. Each spiracle is comprised of two small, broadly oval apertures, each of which is encircled by a delicate ring of chitin from which fingerlike projections extend toward the center of the opening. Frequently the two openings are so closely appressed at the inner ventral border as to give the spiracle a bilobed appearance. The peritreme, so easily distinguished in second- and third-instar larvae, is not apparent. The anal protuberance, located on the ventral side of the last segment, bears two conical, fleshy projections, the anal tubercles. A group of spines is situated in front and behind on the anal protuberance. Two or three rows of spines are present also between the anal protuberance and the lower margin of the posterior cavity. The tubercles bordering the posterior cavity are poorly defined.

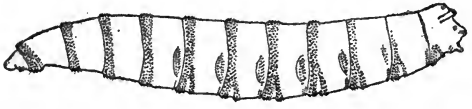

FIGURE 2.—Lateral view of first-instar larva (12 hours old) of *Cochliomyia americana*, × 22.

The cephalopharyngeal mechanism (fig. 3, *A*, *B*) is situated in the cephalic or first apparent segment and in a portion of segment 2. The structure consists of a pair of large pharyngeal sclerites (*phs*) composed of 2 dorsal (*dc*) and 2 ventral (*vc*) cornua and a rather short dorsoanterior projection. The pharyngeal sclerites are apparently not joined dorsoanteriorly as in the second- and third-instar larvae of *Cochliomyia americana* (fig. 6, *A*, *dps*) and in the three instars of *C. macellaria*. The ventral portion of the pharyngeal sclerites extends anteriorly and joins the hypostomal sclerites (*hs*), which in turn articulate with the ventral basal portion of the oral hooks (*oh*). The parastomal sclerites (*pss*), a pair of slender sclerites, extend anteriorly from the pharyngeal sclerites just above

the hypostomal sclerites. The oral hooks (*oh*) consist of 2 elongate sclerites to which are attached a group of about 6 small hooklets. Above and between the oral hooks is an unpaired structure, the hatching spine (*hsp*), which is present only in first-instar larvae. The degree of pigmentation of the cephalopharyngeal sclerites varies with the age of the larva. Length of cephalopharyngeal skeleton from tip of oral hooklets to posterior extremity of dorsal cornua ranging from 0.24 to 0.27 mm, the average of 10 being 0.26 mm; average width at widest point 0.07 mm.

SECOND INSTAR

Larva (fig. 4) more robust than in the first instar. Length and width of newly molted larvae approximately 3.5 and 0.6 mm, respectively; fully developed second-instar larvae measure from 6.3 to 7.4 mm in length and approximately 1.5 mm in width at the widest point.

Heavily armed with large dark spines; larger spines measuring approximately 55μ in length; spines with 1 to 3 points, more often 1 or 2. Anterior margin of segments 2 to 9 completely encircled with a band of spines, while on segment 10 the band is generally, but not always, interrupted by a narrow space on the dorsum. On segment 11 the band is reduced to 2 or 3 rows of smaller spines on the sides and never completely encircles the segment. On segment 12 the spines are confined to the ventral and ventrolateral surfaces.

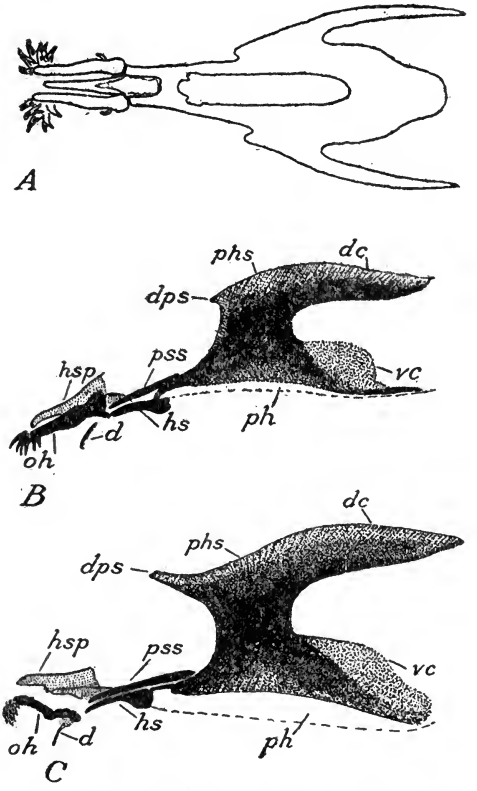

FIGURE 3.—*A*, Ventral view, and *B*, lateral view, of cephalopharyngeal sclerites of first-instar larva (12 hours old) of *Cochliomyia americana*, × 222; *C*, cephalopharyngeal sclerites (lateral view) of first-instar larva (almost fully developed) of *C. macellaria*, × 194; *d*, dental sclerite; *dc*, dorsal cornu; *dps*, dorsopharyngeal sclerite; *hs*, hypostomal sclerite; *hsp*, hatching spine; *oh*, oral hook; *ph*, pharynx; *phs*, pharyngeal sclerite; *pss*, parastomal sclerite; *vc*, ventral cornu.

Ventral and lateral fusiform areas as in the first instar. Posterior margin of segment 11 completely encircled with a band of about 3 rows of smaller, anteriorly recurved spines. On segment 10 there are 2 irregular ventral and lateral rows, and a few scattered spines may extend to the dorsal surface but do not join to form a completely encircling band. A few scattered spines may be present on sides of segments 9 and 8 but are restricted to the venter on segments 7 and 6.

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The anterior spiracles, 2 small fan-shaped structures generally with 7 to 9 fingerlike processes or branches on each, are situated 1 on each side near the base of segment 2. The structure, except for the smaller size, is similar to that of the third instar (fig. 7, *A*). Posterior spiracles (fig. 5, *A*), 2 small plates each with 2 slits partly surrounded by a ring or peritreme, are located in the posterior cavity on the last segment. The peritreme partly surrounding the slits is incomplete ventrad of the slits and quite narrowed and lightly pigmented dorsad of them. Greatest diameter of spiracular plates from 0.134 to 0.168 mm, average about 0.150 mm. The 2 main tracheal trunks are provided with a dark pigment, the pigmented portion extending approximately one-half the length of segment 12.

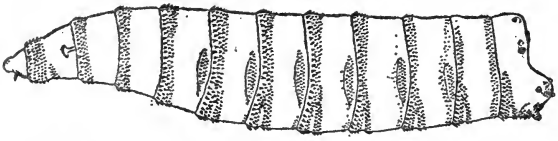

FIGURE 4.—Lateral view of second-instar larva (48 hours old) of *Cochliomyia americana*, × 12.

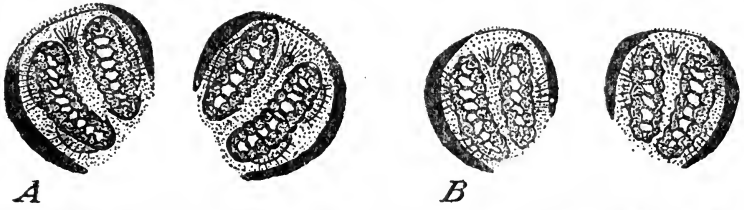

FIGURE 5.—Posterior spiracles of second-instar larva: *A*, *Cochliomyia americana*; *B*, *C. macellaria*; × 148.

Posterior cavity more depressed than in the first instar; upper border of the cavity provided with 3 pairs of rather low, broadly rounded, fleshy processes; the inner and outer pair equal, the median pair poorly defined. On the lower border of the cavity the median pair somewhat the largest and the outer pair larger than the inner, which is poorly defined. Relative positions similar to those in the third instar (fig. 8, *A*). Anal protuberance rather small, with 2 prominent anal tubercles. Spines on anal protuberance similar to those in the third instar (fig. 8, *A*).

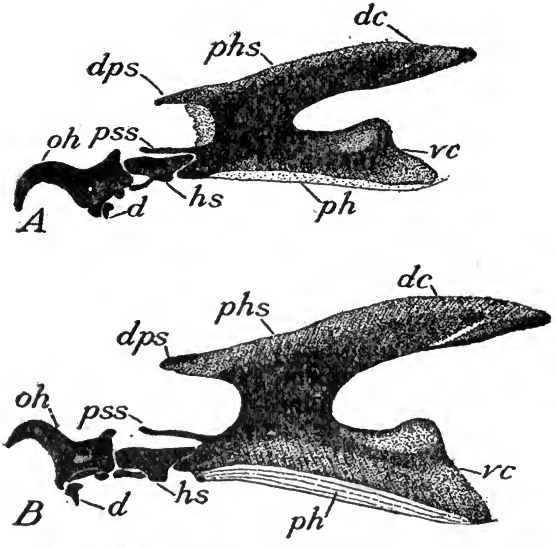

FIGURE 6.—Lateral view of cephalopharyngeal sclerites of second-instar larva: *A*, *Cochliomyia americana*; *B*, *C. macellaria*; × 94; see explanation of symbols under figure 3.

Cephalopharyngeal mechanism as in figure 6, *A*. The oral hooks are 2 prominent sclerites with a more or less rectangular basal portion with 2 long, broadly curved hooks. The pharyngeal sclerites are produced dorsoanteriorly and are connected by the dorsopharyngeal sclerites (*dps*). The cephalopharyngeal sclerites become darker as the larvae grow older. Length of cephalopharyngeal skeleton from 0.670 to 0.688 mm; average of 10, 0.674 mm.

THIRD INSTAR

Form rather robust, tapering toward the anterior extremity from the sixth segment and slightly tapering toward the posterior end on the last three segments (fig. 7, *A*). Length from 6.4 to 17 mm and

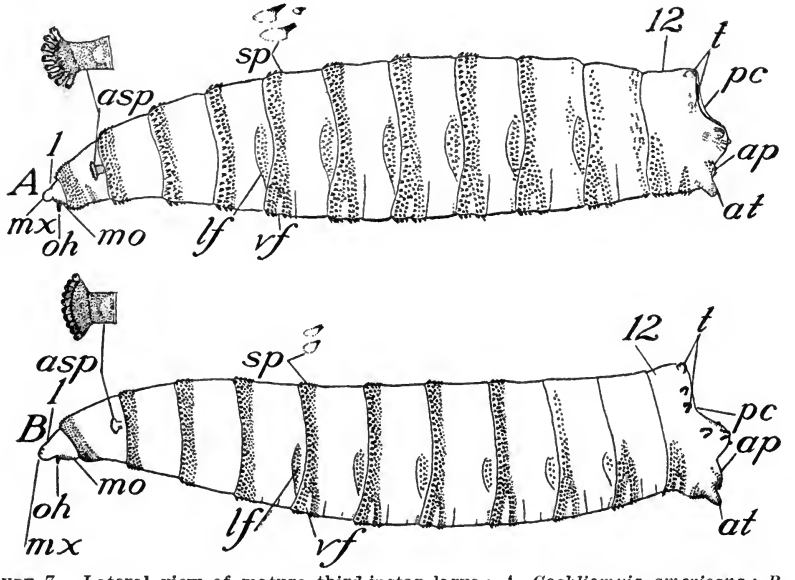

FIGURE 7.—Lateral view of mature third-instar larva: *A*, *Cochliomyia americana*; *B*, *C. macellaria*; × 6; anterior spiracles and some spines are shown more enlarged; *ap*, anal protuberance; *asp*, anterior spiracle; *at*, anal tubercle; *lf*, lateral fusiform area; *mo*, mouth; *mx*, maxillary lobe; *oh*, oral hook; *pc*, posterior cavity; *sp*, spines; *t*, tubercles; *vf*, ventral fusiform area; *1*, first (or cephalic) segment; *12*, twelfth segment.

width from 1.6 to 3.5 mm. Fully matured larvae are generally 15 to 16 mm in length. Newly molted larvae are creamy white in color; mature larvae have a slight reddish tinge.

Heavily armed with large 1- to 3-pointed spines; more often there are 1 or 2 points to each. Anterior margin of segments 2 to 9 completely encircled with a band of spines. Spines arranged in irregular rows, those in the anterior rows the largest. On segment 10 the anterior band of spines is somewhat narrowed and generally interrupted on the dorsum as in the second instar. On segment 11 the anterior band never completely encircles the segment and the spines on the sides are smaller and greatly reduced in numbers. Spines on segment 12 are restricted to the ventral and ventrolateral surfaces. The posterior margin of segment 11 is provided with a loose band of 2 or 3 rows of anteriorly curved spines. On segment 10 a few scattered spines may be present laterally and dorsolaterally

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but are always present ventrally and ventrolaterally. On segments 7 to 9 the spines at the posterior margin are reduced to 1 or 2 rows and confined to the ventral surfaces.

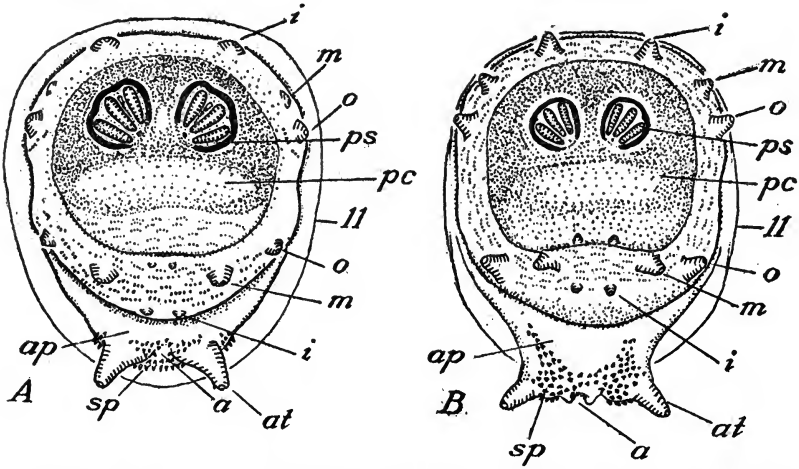

FIGURE 8.—Posterior view of twelfth or last apparent segment of third-instar larva: *A*, *Cochliomyia americana*; *B*, *C. macellaria*; × 16; *a*, anus; *ap*, anal protuberance; *at*, anal tubercle; *i*, inner tubercle; *m*, median tubercle; *o*, outer tubercle; *pc*, posterior cavity; *ps*, posterior spiracle; *sp*, spines on anal protuberance; *11*, eleventh segment.

Anterior spiracles (fig. 7, *A*) provided with from 6 to 11 finger-like branches; the usual number is 7 to 9; average of 120 spiracles, 8.3 branches per spiracle. The posterior spiracles (fig. 8, *A*, and more enlarged in fig. 9, *A*) are large, each with a prominent, dark, pigmented peritreme which apparently does not completely surround the 3 more or less oval slits. Greatest diameter of spiracular plate from 0.39 to 0.46 mm; average of 10, 0.43 mm. The 2 main tracheal trunks are darkly pigmented, the pigmented portion extending anteriorly to the tenth or ninth segment (fig. 10, *A*).

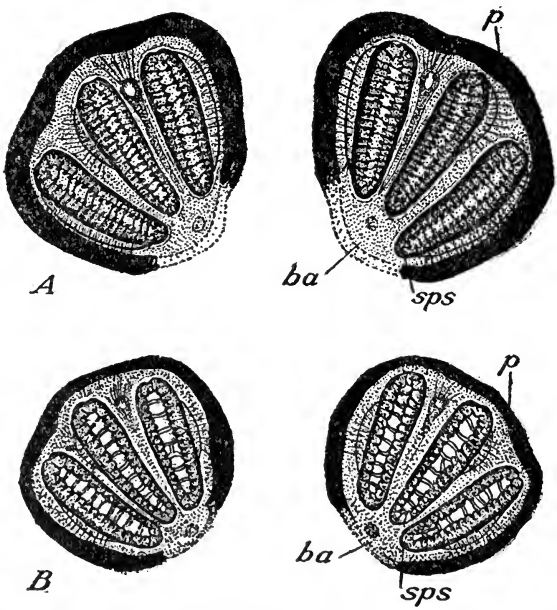

FIGURE 9.—Posterior spiracles of third-instar larva: *A*, *Cochliomyia americana*; *B*, *C. macellaria*; × 84; *ba*, button area; *p*, peritreme; *sps*, spiracular slits.

Upper border of posterior cavity (fig. 8, *A*) bearing 3 pairs of low, broadly rounded tubercles; inner and outer pairs approximately equal; median pair greatly reduced and closely approximated to the outer tubercle.

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Lower border of cavity provided with similar tubercles; the median pair the largest and the outer pair larger than the inner pair. An

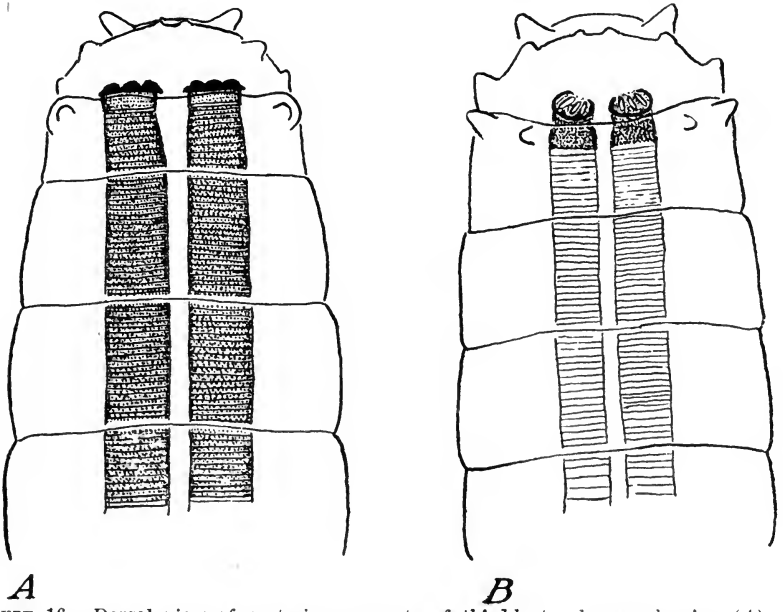

FIGURE 10.—Dorsal view of posterior segments of third-instar larvae showing (*A*) pigmented tracheal trunks of *Cochliomyia americana* and (*B*) unpigmented tracheal trunks of *C. macellaria*; × 13.

additional pair of small tubercles situated medially near the lower margin of the posterior cavity. Anal protuberance (fig. 8, *A*) comparatively small, with 2 prominent, conical anal tubercles. Rather prominent spines located on the anal protuberance in front and behind. Short rows of 3 to 4 minute spines situated on the lower portion of the depressed area and on lower margin of posterior cavity (fig. 8, *A*).

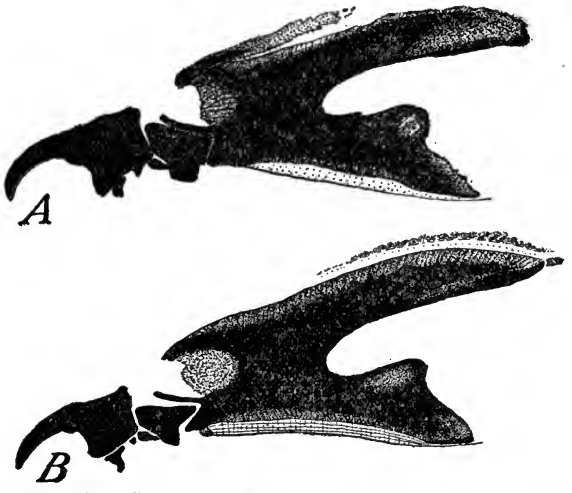

FIGURE 11.—Cephalopharyngeal sclerites of mature third-instar larva (lateral view): *A*, *Cochliomyia americana*; *B*, *C. macellaria*; × 49.

Cephalopharyngeal mechanism as in figure 11, *A*. Although larger and quite different in appearance, the parts are essentially the same as in the second instar. The narrow pigmented strip arising at the dorsoanterior margin of the pharyngeal sclerites and extend-

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ing posteriorly is not seen in younger third-instar larvae, but as the larvae mature this part gradually becomes more distinct. The entire cephalopharyngeal mechanism becomes more heavily pigmented and rougher in appearance as the larvae mature. Length of cephalopharyngeal mechanism from 1.40 to 1.56 mm; average of 10, 1.49 mm.

COCHLIOMYIA MACELLARIA FAB.

FIRST INSTAR

Size and general form similar to those of *Cochliomyia americana*. Spines small, brownish in color; larger spines approximately 6μ in length. All spines with a single point.

Last segment slightly depressed behind. Posterior spiracles similar to those of *Cochliomyia americana*. Tubercles bordering the posterior cavity poorly defined.

Cephalopharyngeal mechanism (fig. 3, *C*) differing significantly from that of *Cochliomyia americana*. Pharyngeal sclerites with a prominent dorsoanterior projection which joins at the anterior extremity. The hatching spine is broader and the oral hooks differ greatly in structure from those of *C. americana*. The oral hooks consist of a pair of irregular, elongate sclerites with a large number of small hooklets closely grouped at the anterior extremity. The cephalopharyngeal skeleton is considerably larger than in *C. americana*, the length ranging from 0.33 to 0.34 mm; average of 10, 0.336 mm. Average width at widest point 0.125 mm.

SECOND INSTAR

Larva slightly less robust than in *Cochliomyia americana*. Spines small; length of larger spines approximately 20μ. Spines in the anterior rows of each band generally with 2 and occasionally 3 points; those in the posterior portion of the band more often with 1 point. Anterior margin of segments 2 to 9 completely encircled with spines; on segment 10 the band is interrupted on the dorsum, and on segments 11 and 12 the spines are restricted to the ventral and ventrolateral regions. Spines wanting on dorsum and sides at posterior margin of segments, thus differing from *C. americana*, in which the posterior margin of segments 11 and 10 is armed with several rows of spines on lateral and dorsal surfaces.

Anterior spiracles more often with 9 or 10 branches. Except for the smaller size, the anterior spiracles are similar to those of the third instar (fig. 7, *B*). Posterior spiracles (fig. 5, *B*) more lightly pigmented and smaller than those of *Cochliomyia americana*; average greatest diameter approximately 0.120 mm. Tracheal trunks leading from the posterior spiracles not pigmented.

Tubercles on border of posterior cavity larger and more conspicuous than in *Cochliomyia americana*. The general appearance of the last segment, although smaller, is essentially the same as in the third instar (fig. 8, *B*).

Cephalopharyngeal skeleton as in figure 6, *B*. The oral hooks are comparatively short and not so broadly curved as in *Cochliomyia*

americana. Other differences are readily apparent by comparing the figures. Length of cephalopharyngeal skeleton from 0.73 to 0.80 mm; average of 10, 0.78 mm. Average width approximately 0.3 mm.

THIRD INSTAR

Form (fig. 7, *B*) less robust and slightly smaller than *Cochliomyia americana*. Spines comparatively small, with from 1 to 3 points, more often with 2. Anterior margin of segments 2 to 9 completely encircled with bands of spines arranged in more regular rows than in *C. americana*. On segment 10 the band is interrupted on dorsum, and on segments 11 and 12 the spinose area is restricted to the ventral and ventrolateral regions. Spines wanting on posterior margin of segments, except for 1 or 2 rows of small spines on venter of segments 7 to 12. Anterior spiracles short, with rather short branches (fig. 7, *B*), the number of branches varying from 8 to 12, more often 9 to 11, average of 120 spiracles 9.81 branches per spiracle. Posterior spiracles (figs. 8, *B*, and 9, *B*) smaller and more rounded than in *C. americana*. Greatest diameter of spiracles from 0.342 to 0.370 mm; average of 10, 0.356 mm. Tracheal trunks leading from the posterior spiracles not pigmented (fig. 10, *B*).

Posterior cavity outlined with conspicuous conical tubercles (fig. 8, *B*); the inner and outer pairs on upper margin equal in size, the median pair smaller. On the lower margin the outer pair slightly larger than the median; the inner pair smaller than the median. An additional pair of small tubercles is situated medially near the lower margin of the posterior cavity. Anal protuberance (fig. 8, *B*) large, with the two prominent, conical anal tubercles. Spines on anal protuberance as shown in the figures. A more or less V-shaped group extending upward on the outer side. Border of the posterior cavity armed with numerous rows of 3 or 4 minute spines.

Cephalopharyngeal mechanism as in figure 11, *B*. The oral hooks are smaller than in *Cochliomyia americana*; the pharynx is more or less ribbed, whereas in *C. americana* it is smooth. Pharyngeal sclerites large, with the dorsal cornua slightly elevated. The strip of pigmented material just above the dorsal cornua is present in varying amounts only in the older third-instar larvae. Length of cephalopharyngeal skeleton from 1.43 to 1.63 mm; average of 10, 1.56 mm.

SUMMARY OF THE CHARACTERISTICS DIFFERENTIATING THE LARVAE OF C. AMERICANA AND C. MACELLARIA

FIRST INSTAR

C. americana	*C. macellaria*
1. General appearance of cephalopharyngeal sclerites as in figure 3, *A*, *B*.	1. General appearance of cephalopharyngeal sclerites as in figure 3, *C*.
2. Smaller cephalopharyngeal mechanism; average length 0.260 mm, average width at widest point 0.069 mm.	2. Average length of cephalopharyngeal mechanism 0.336 mm, average width at widest point 0.125 mm.
3. Spines large; larger spines approximately 20μ in length. Spines generally heavily pigmented.	3. Spines smaller; larger spines approximately 6μ in length. Spines generally lighter in color.

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SECOND INSTAR

C. americana	*C. macellaria*
1. General appearance of cephalopharyngeal sclerites as in figure 6, *A*.	1. General appearance of cephalopharyngeal sclerites as in figure 6, *B*.
2. Average length of cephalopharyngeal mechanism 0.674 mm.	2. Average length of cephalopharyngeal mechanism 0.780 mm.
3. Posterior margin of segment 11 provided with a completely encircling band of spines; on segment 10, spines wanting only on dorsum.	3. Posterior margin of segments devoid of spines except on ventral surface.
4. Tracheal trunks leading from posterior spiracles dark in color from junction with spiracles through approximately one-half length of last segment.	4. Tracheal trunks leading from posterior spiracles not pigmented.
5. General appearance of last segment, except for the smaller size, closely resembling that of the third instar, which see (fig. 8, *A*).	5. General appearance of last segment, except for the smaller size, closely resembling that of the third instar, which see (fig. 8, *B*).
6. Ventral wall of pharynx smooth.	6. Ventral wall of pharynx ribbed.
7. Spines large; larger spines approximately 55μ in length. Spines generally dark brown to black.	7. Spines smaller; larger spines approximately 20μ in length. Spines brownish.
8. General appearance of posterior spiracles as in figure 5, *A*. Comparatively large, average greatest diameter 0.150 mm.	8. General appearance of posterior spiracles as in figure 5, *B*. Comparatively small, average greatest diameter 0.120 mm.
9. Anterior spiracles more often with 7 to 9 branches.	9. Anterior spiracles more often with 9 to 11 branches.

THIRD INSTAR

C. americana	*C. macellaria*
1. General appearance of cephalopharyngeal sclerites as in figure 11, *A*.	1. General appearance of cephalopharyngeal sclerites as in figure 11, *B*.
2. Tracheal trunks leading from posterior spiracles dark in color at junction with posterior spiracles and extending to tenth or ninth segment (fig. 10, *A*).	2. Tracheal trunks not pigmented (fig. 10, *B*).
3. Posterior margin of segment 11 provided with a completely encircling band of spines.	3. Posterior margin of segments devoid of spines except on ventral surface.
4. Appearance of posterior spiracles as in figure 9, *A*. Average greatest diameter of posterior spiracles 0.427 mm.	4. Appearance of posterior spiracles as in figure 9, *B*. Average greatest diameter of posterior spiracles 0.356 mm.
5. Structure of last segment as in figure 8, *A*.	5. Structure of last segment as in figure 8, *B*.
6. Spines large; larger spines approximately 130μ in length.	6. Spines smaller; larger spines approximately 80μ in length.
7. Anterior spiracles more often with 7 to 9 branches. Branches longer and more widely separated (fig. 7, *A*.)	7. Anterior spiracles more often with 9 to 11 branches. Branches comparatively shorter and closer together (fig. 7, *B*).
8. Ventral wall of pharynx smooth.	8. Ventral wall of pharynx ribbed.

DURATION OF LARVAL INSTARS OF COCHLIOMYIA AMERICANA

Experiments to determine the duration of each instar indicate that this is considerably influenced by the size and nature of the

wound and the number of larvae present. The weighted mean larval feeding period for 551 larvae reared in a large wound was 149.8 hours, while that for 485 larvae reared in a small wound on the opposite side of the same animal and infested at the same time was 214.2 hours.

The weighted means of the duration of the total larval stage in each of six cases in sheep at Sonora, Tex., during May and June of 1934, were 174.5, 107.5, 103.8, 139.3, 141.2, and 164.1 hours. At Menard, Tex., observations on cattle infested in nature showed that the larvae continue to feed for 82 to 239 hours before they leave the wound.

H. O. Schroeder and C. N. Smith, of this Bureau, working with an infested sheep at Washington, D. C., during March 1935, obtained the results shown in table 2 on the duration of the various instars.

TABLE 2.—*Duration of the larval instars of Cochliomyia americana in sheep, Washington, D. C., Mar. 1, 1935*

Age (hours)	Larvae removed from wounds					
	First instar		Second instar		Third instar	
	Number	*Percent*	*Number*	*Percent*	*Number*	*Percent*
24	17	100	0	0	0	0
30	10	58.8	7	41.2	0	0
42	1	5.3	18	94.7	0	0
48	0	0	19	100	0	0
54	0	0	49	100	0	0
60	0	0	20	100	0	0
66	0	0	43	97.7	1	2.3
72	0	0	59	93.6	4	6.4
78	0	0	35	72.9	13	27.1
84	0	0	24	55.8	19	44.2
90	0	0	6	50	6	50.
96	0	0	3	50	3	50.
102	0	0	1	16.7	5	83.3
117	0	0	2	40	3	60.
132	0	0	0	0	10	100
183 [1]	0	0	0	0	12	100
195 [2]	0	0	0	0	6	100

[1] Age at which first mature larvae left wound.
[2] Age at which last mature larvae left wound.

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Data obtained on the duration of larval instars in six infestations of sheep at Sonora, Tex., during the summer of 1934 are given in table 3.

TABLE 3.—*Variations in the duration of larval instars of Cochliomyia americana in sheep, Sonora, Tex., May and June 1934*

Case no.	Age of larvae when removed from wound		Larvae removed from wound			Larvae leaving wound to pupate				Larvae maturing in wound
			First instar	Second instar	Third instar	First larvae leaving wound		Last larvae leaving wound		
	Hours	*Minutes*	*Number*	*Number*	*Number*	*Numoer*	*Age in hours*	*Number*	*Age in hours*	*Number*
6	1	45	10							
	28	0		7						
	50	30		1	6	21	99.5	1	124.5	81
	73	45			9					
	98	45			9					
8	25	20	16							
	49	20		11						
	55	0		7	2					
	69	40			5					
	75	40			8					
	94	40			5					
	100	40			5					
9	3	0	11							
	24	0	7							
	49	30		9						
	54	30		17						
	73	30		9	4					
	121	30			3					
12	36	0		7						
	48	0		8						
	54	0		2	6					
	60	0		2	5	50	130	2	155	138
	66	0			6					
	78	0			5					
13	32	50		12						
	44	50		18						
	50	50		5	5					
	56	50		3	7	6	126	1	154	51
	62	50		1	6					
	74	50		1	2					
14	32	50	23	10						
	44	50		44						
	50	50		50						
	56	50		42		1	129	3	198	863
	62	50		34	3					
	74	50		2	23					
	80	50		10						

In one case in a sheep, where the wound was infested with less than 100 larvae, it was observed that some of the larvae changed to the second instar in 18 hours.

The results of observations to determine at what time of day mature larvae leave the wound are shown in table 4. The animals used in this experiment were kept in a screened insectary and watched constantly until all maggots had left the wounds.

TABLE 4.—*Observations on time of day larvae of Cochliomyia americana leave wounds in sheep, Sonora, Tex., May and June 1934*

Time of day	Case 3			Case 6		Case 6a		Case 12		Case 13		Case 14				Total
	May—			June—		June—		June—		June—		June—				
	15	16	17	4	5	15	16	26	27	26	27	26	27	28	29	
	No.	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*
12 to 4 a. m.														3	2	5
4 to 5 a. m.														3		3
5 to 6 a. m.														3		3
6 to 7 a. m.													1	8		9
7 to 8 a. m.					1									11		12
8 to 9 a. m.					5				10				19	90	1	125
9 to 10 a. m.		4			5				19		10		38	159	2	237
10 to 11 a. m.	1	4			9	22	3	50	21	6	12		38	99	3	268
11 to 12 a. m.	1	19	1	21	4	36	16	18	2	8	4		94	69		293
12 to 1 p. m.	5	10		6	1	15	3	8					31	20		99
1 to 2 p. m.	6	6		13		11		6			3	1	36	34		116
2 to 3 p. m.	7	1		11		11	2	1			1	2	36	4		76
3 to 4 p. m.	6			3		4		2		5		4	25	1		50
4 to 5 p. m.				1				1		2		4	11	1		20
5 to 6 p. m.				1								1	1	1		4
6 to 7 p. m.																
7 to 8 p. m.													2			2
8 to 10 p. m.													4			4
10 to 12 p. m.													1			1
Total	26	44	1	56	25	99	24	86	52	21	30	12	337	506	8	1,327

Larvae begin feeding on the tissues of the wound as soon as they hatch. Melvin has demonstrated experimentally that newly hatched larvae are capable of penetrating the unbroken skin of rabbits and guinea pigs. This has never been observed to take place in nature, but numerous infestations occur among range sheep in the external lachrymal fossae of the eyes in which there is no evidence of skin abrasions.

After the larvae penetrate the tissues, they assume the characteristic head-downward position, with the posterior end bearing the spiracles remaining in contact with the air. In cases where the wound is so located that the exudate collects in the cavity, the larvae periodically extrude the posterior tips of their abdomens above the surface of the liquid for the purpose of obtaining air. When once the larvae of *Cochliomyia americana* become embedded in the flesh, they do not move about in the wound as do *C. macellaria* and other wound-inhabiting species.

THE PREPUPA

The length of the prepupal period varies considerably and is apparently dependent to some extent upon the environment in which the mature larvae find themselves at the time they drop from the wound. It has been noted to range from 7 to 76 hours. The weighted mean prepupal period for all mature larvae which had dropped naturally from five cases in sheep at Sonora, Tex., during June 1935 is given in the following tabulation:

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Number of mature larvae dropping from wound	*Weighted mean prepupal periods, hours*
81	20.7
120	18.7
135	17.3
50	15.3
863	20.0

As soon as the larvae observed in this test dropped from the wound they were placed in a pint mason jar half full of slightly moistened sand. The jars were kept in an open insectary.

Upon leaving the wound, the larvae immediately seek some sheltered place in which to pupate. They either crawl under some object or burrow into the soil. The results of experiments conducted by Melvin to ascertain how deeply the larvae would penetrate into several types of soil are given in table 5. These tests were conducted by placing each type of soil in a wooden container 6 inches square and 38 inches high, waterproofed at the sides and open at each end, and standing the container upright in 3 inches of water. The depth of penetration by *Cochliomyia macellaria* is also given for comparison.

TABLE 5.—*Depth of penetration by Cochliomyia americana and C. macellaria larvae in soil of different types*

Species	Clay		Heavy black soil		Sand		Gravel	
	Weighted mean depth	Maximum depth	Weighted mean depth	Maximum depth	Weighted mean depth	Maximum depth	Weighted mean depth	Maximum depth
	Inches	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
C. americana	7.77	17	2.48	13	2.25	6	1.87	3
C. macellaria	1.35	5	1.41	4	1.76	3	----------	----------

In another experiment, heavy black loam was tightly packed in a glass cylinder 5½ inches in diameter and 5 inches high by tamping the soil with a heavy stick. Larvae of *Cochliomyia americana* penetrated into this medium to depths ranging from five-sixteenths of an inch to 1½ inches, the weighted average being fifteen-sixteenths of an inch. When the cylinder was loosely filled with the same kind of soil, the depth of penetration ranged from six-sixteenths of an inch to 3 inches, the weighted average being $1\frac{5}{16}$ inches.

The first experiment was conducted in the laboratory at a fairly constant temperature (86° F.) during February 1935, at Dallas, Tex. The second experiment, by H. O. Schroeder and C. N. Smith, was made on April 1, 1935, in a room temperature of about 80°. It must be remembered that these tests were made under purely artificial conditions and give only an indication of the ability and tendency of the larvae to penetrate soil.

THE PUPA

The pupa of *Cochliomyia americana* is shown in figure 12. Normally it is of a dark brown color and is much larger and more barrel-shaped than that of *C. macellaria*. Ten specimens averaged 10.2 mm in length and 4.3 mm in width.

The duration of the pupal stage is subject to considerable variation. Under conditions in which the pupae were exposed to the influence of outside weather factors, the length of this period ranged from 167 hours (about 7 days) during the summer to 54 days during the winter; under controlled laboratory conditions of 100 percent relative humidity, Melvin determined that the period ranged from 142.2 hours at 94° F. to 760.4 hours at 59°.

Under controlled temperature and humidity the pupal period is almost twice as long as that of *Cochliomyia macellaria*, as determined by Melvin's experiments.

The relation between air and soil temperatures and their effect on the duration of the pupal stage were studied by R. A. Roberts at Uvalde, Tex., during January, February, and March 1935. On January 19, pupae were buried 4 inches below the surface of the soil. Maximum and minimum temperatures of air and soil were recorded daily until either the flies emerged or the pupae had died. On March 1, 3, and 4, or 41, 43, and 44 days later, from the pupae placed in the soil, 9.1, 4.5, and 22.7 percent, respectively, of flies emerged. The remainder (63.7 percent) of the pupae were dead. The highest and lowest daily maximum and minimum air and soil temperatures recorded during the period from the time the pupae were placed in the soil until the adults emerged are as follows:

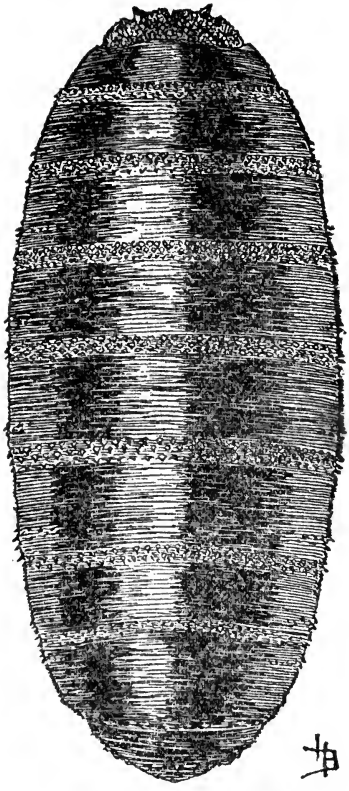


FIGURE 12.—Pupa of *Cochliomyia americana*, × 10.

	° F.
Highest daily maximum air temperature	83
Lowest daily maximum air temperature	37
Highest daily minimum air temperature	58
Lowest daily minimum air temperature	18
Highest daily maximum soil temperature	70
Lowest daily maximum soil temperature	48
Highest daily minimum soil temperature	63
Lowest daily minimum soil temperature	40

THE ADULT

The adult of *Cochliomyia americana* has a deep greenish-blue metallic color and may be readily distinguished from species belonging to other genera of blowflies in the United States by the characteristic yellow, orange, or reddish face, and the the three dark

stripes on the dorsal surface of the thorax (pl. 1). Because of the similarity in external characters between *C. macellaria* and *C. americana*, however, it is much more difficult for the inexperienced observer to separate these two species. Females of *C. macellaria* may usually be distinguished from those of *C. americana* by the fact that the basicostal scale (a small sclerite at the base of the wing) of the former is of a yellowish color whereas in the latter this part is black. Also, in *C. macellaria* the underside of the abdomen along the mid-line is covered by a dense whitish pruinosity which, on the last visible segment of the abdomen, appears as two lateral whitish spots when the specimen is viewed from above. This character is absent in *C. americana*.

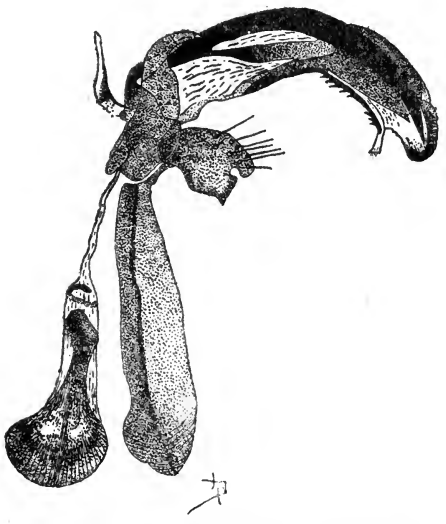


FIGURE 13.—Male genitalia of *Cochliomyia americana*.

The most reliable means of telling the males of the two species apart is by an examination of the genital apparatus. The difference between them is shown in figures 13 and 14.

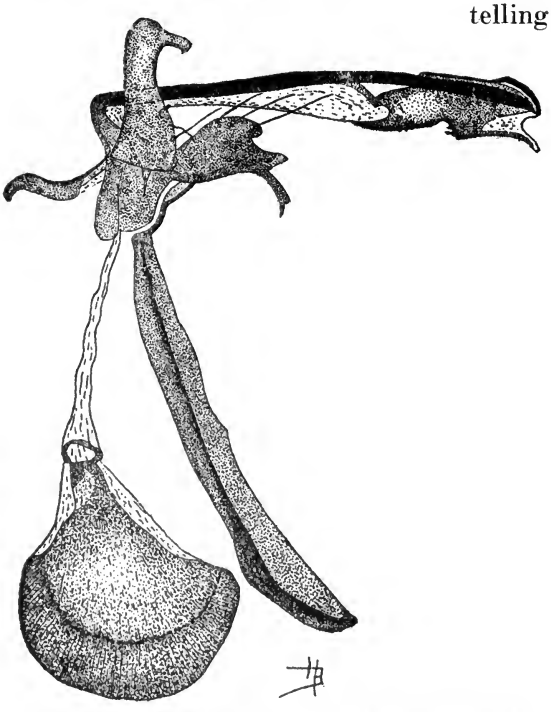
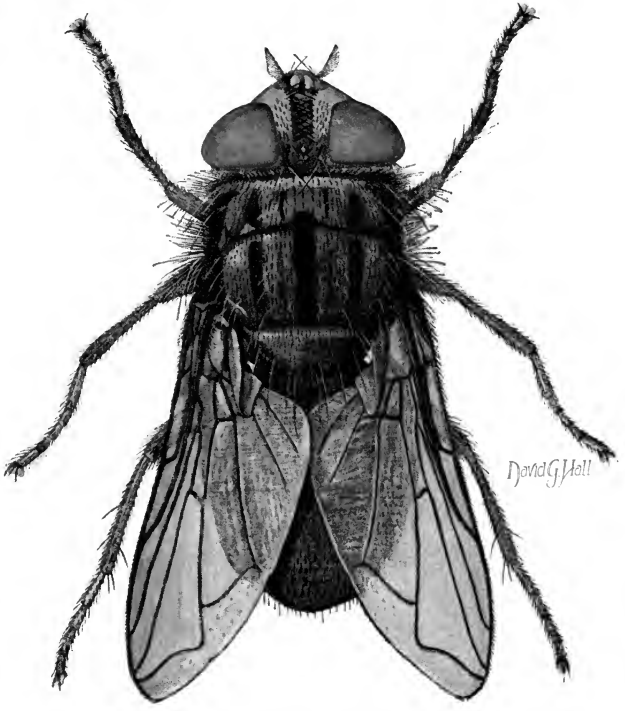


FIGURE 14.—Male genitalia of *Cochliomyia macellaria*.

In most cases it has been observed that the flies emerge from the puparia early in the morning between the hours of 4 and 7 o'clock, and are ready to take wing a few hours later. Generally from 5 to 10 days must elapse after emergence before the female is capable of depositing fertile eggs.

As previously stated, the eggs, according to the records, are deposited in batches of 10 to 393. The female is able to deposit as many as 300 eggs in 4 to 6 minutes. Tests have been made to determine the total number of fertile eggs a female is capable of



Negatives furnished through courtesy of M. S. Yeomans.

ADULT SCREW WORM FLY (COCHLIOMYIA AMERICANA).

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laying. The maximum number laid by a single female kept in captivity and fed on meat, sugar water, and banana under an average room temperature of 80° F., as determined by H. O. Schroeder and C. N. Smith, is shown in table 6. This fly lived for a period of 65 days, which is the greatest longevity record so far obtained on flies of this species kept in captivity. When this fly died, its abdomen was dissected and found to contain approximately 250 almost fully developed eggs. As a rule, when the flies are kept in cages they are short-lived. A large number die within 7 days and few of them live longer than 30.

TABLE 6.—*Oviposition record of one female of Cochliomyia americana*

Batch no.	Eggs in batch [1]	Age of fly at time of laying each batch	Batch no.	Eggs in batch [1]	Age of fly at time of laying each batch	Batch no.	Eggs in batch [1]	Age of fly at time of laying each batch
	Number	*Days*		*Number*	*Days*		*Number*	*Days*
1	336	13	6	234	42	11	183	56
2	283	17	7	229	46	12	194	60
3	264	22	8	286	49			
4	294	31	9	4	52	Total	2,853	
5	329	39	10	217	53			

[1] Each batch contained a high percentage of fertile eggs.

When kept in cages in insectaries or out of doors, adults are not so active as other species of flies under like conditions. They prefer to remain motionless, resting on the walls or top of the cage the greater part of the time; in nature, however, they appear to be strong fliers. During the hot months of summer and early fall the flies are more numerous and active about animals, and it is during these seasons that the largest number of infestations usually occur. The lowest temperature at which females have been observed ovipositing in nature was 65° F., but it is quite possible that some of them will infest animals at temperatures lower than this.

Adults kept in captivity feed readily on sweets of various kinds, blood, meat, bananas, and the nectar from flowers growing in the cage; in nature, they have been observed to feed on wounds, fresh manure, and fresh meat.

According to records obtained by Melvin, the total life cycle of *Cochliomyia americana*, that is, from the time the eggs are laid until females developing from these eggs are ready to oviposit, is about 24 days at an average air temperature of 72° F. during September and October at Dallas, Tex. This is nearly twice the time required for *C. macellaria* to complete its life cycle.

The comparative abundance of *Cochliomyia americana* and *C. macellaria* in nature is 1 of the former to 590 of the latter, as determined by the attractiveness of fresh uninfested and infested necrotic wounds in cattle at Menard, Tex., by H. E. Parish, during the summer and fall of 1934. This ratio is based on a total of 66,155 of the two species visiting 6 wounds which were exposed for a period of 2 days each. The ratio of the species taken in a standard meat-baited flytrap during a 7-day test in which 80,159 *Cochliomyia* were caught, was 1 *C. americana* to 2,427 *C. macellaria.*

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EFFECT OF COLD UPON EGGS, PREPUPAE, PUPAE, AND ADULTS

The results of experiments by H. O. Schroeder and C. N. Smith to determine the effect of cold on the various stages of *Cochliomyia americana* are given in tables 7 and 8. In the tests shown in table 7, specimens were placed in an electric refrigerator and the temperature was run down to the desired point; then the current was cut off and the refrigerator allowed to warm gradually. When the temperature had risen to 50° F., the specimens were removed and kept at a room temperature of about 80°. In some instances a few of the specimens were held at 40° for a number of hours before being kept at room temperature. The time required to run the temperature in the refrigerator down to the desired point ranged from 3 to 5½ hours. One-half of each egg mass listed in table 7 was kept at room temperature for a check on the viability of each batch. All the check eggs hatched. Similarly, an equal number of prepupae and pupae which had spent their larval stage in the same wound as those used in the test served as check specimens. These all produced normal adults. Adults from the same source as those used in the test were all normal specimens.

TABLE 7.—*Effect of cold on eggs, prepupae, pupae, and adults of Cochliomyia americana*

Stage of fly exposed	Specimens in test	Lowest temperature to which specimens were exposed	Total time required for temperatures to reach lowest point and to rise to 50° F.	Results
	Number	° *F.*	*Hours*	
Eggs	450 (3 lots [1])	32	7½	2 lots hatched; 1 did not.
	450 (3 lots)	28	9	3 lots did not hatch.
	600 (4 lots)	26	10	2 lots hatched; 2 did not.
	450 (3 lots)	24	7½	1 lot hatched; 2 did not.
	300 (2 lots)	20	9	2 lots did not hatch.
Prepupae	6	[2] 20	[3] 3	1 died; 5 lived to adult stage (all males).
	10	[2] 15	7½	3 died; 7 lived to adult stage; females laid fertile eggs.
	6	15	7½	3 died; 3 pupated but died later; no adults.
	10	[2] 13	9	2 died; 8 pupated; 4 adults emerged.
	10	13	9	3 died; 7 pupated but died later; no adults.
	10	[2] 12	12	4 died; 6 pupated but died later; no adults.
	10	[2] 12	12	1 died; 9 pupated; 1 male emerged.
	10	12	12	5 died; 5 pupated but died later; no adults.
	10	[2] 11	13	3 died; 7 pupated but died later; no adults.
	10	11	13	9 died; 1 pupated but died later; no adults.
	6	16	15	6 died.
	6	10	20	Do.
	6	[2] 10	24	Do.
Pupae	6	[2] 20	8	6 adults emerged and laid eggs.
	10	[2] 15	12	4 adults emerged and laid fertile eggs; 6 died.
	6	[2] 13	5	2 adults emerged and laid eggs; 4 died.
	6	[2] 13	8	6 died.
	10	[2] 11	14	10 died.
	10	[2] 11	[4] 27	Do.
Adults	6	20	7	3 males lived; 2 females died; 1 lived and laid eggs.
	10	18	8	10 died.
	6	18	8	6 died.
	10	15	10	10 died.
	10	10	[5] 22½	Do.
	10	10	[6] 22½	Do.
	10	10	17½	Do.

[1] Each lot consisted of one-half of an egg mass and contained about 150 eggs.
[2] Specimens placed in half-pint paper cup containing sawdust; all others in open cups.
[3] Specimens held at 40° F. for 15 hours.
[4] Specimens held at lowest temperature 16 hours.
[5] Specimens held at lowest temperature 4 hours and at 40° F. for 13 hours.

By using a thermocouple and galvanometer, the temperatures at which the body fluids of the different stages of *C. americana* freeze was determined. These temperatures are given in table 8.

TABLE 8.—*Undercooling and freezing points of eggs, prepupae, and adults of Cochliomyia americana*

Stage and number of specimens	Average undercooling point	Average freezing point	Effect on specimens
	° F.	° F.	
1 egg mass	16	17	All failed to hatch.
7 prepupae	13	23	All died.
8 pupae	18	20	3 adults emerged.
3 male adults	19	21	All lived.
3 female adults	21	23	All lived and laid fertile eggs.

BREEDING PLACES

At the present time all the evidence at hand indicates that in nature *Cochliomyia americana* larvae begin their development only in the tissues of live animals.

Of approximately 67,000 flies of the genus *Cochliomyia* reared by H. E. Parish from carcasses of cattle, sheep, and rabbits exposed in nature at Menard, Tex., when adults of *C. americana* were active, all were *C. macellaria*. At Sonora, Tex., no adults of *C. americana* were found in samples of 2,000 flies reared from each of 5 rabbit carcasses that were exposed for 3 days after the animal had been dead for the following periods: 10 minutes and 12, 36, 60, and 84 hours.

While it is possible under laboratory conditions, by a method developed by Melvin, to rear the flies from the egg to the adult stage on such media as hard-boiled eggs and raw lean beef kept at a constant temperature of 94° F., under natural conditions oviposition has never been observed to take place on carcasses, pieces of meat, or other materials. Females kept in cages in the laboratory under room temperatures of 80° have deposited eggs on fresh lean meat, and they oviposit readily on this medium at a temperature of 95°.

Numerous observations have shown that larvae which have begun their development in live animals are able to complete their growth in dead tissue. Results of three tests conducted by Melvin, in which guinea pigs were killed at 24-hour intervals after becoming infested, showed that the minimum ages of the larvae at which they continued development in the carcass were 36, 48, and 96 hours; during these periods the average daily mean temperatures were 75.6°, 86.0°, and 52.4° F., and the average daily maximum temperatures were 88°, 86°, and 64°, respectively. Observations indicate that under such conditions the larvae must molt to the second instar before they can complete their development.

SUMMARY

Cochliomyia americana and *C. macellaria* are two species of screw worms which infest wounds in man and animals. The former, because of its close similarity in outward appearance to the latter and more common species, remained unrecognized for a number of years. Its discovery necessitated a restudy of the biology, habits, and relative economic importance of the two species.

Present data indicate that in nature *Cochliomyia americana* is a primary, obligatory parasite and initiates the majority of screw worm infestations in warm-blooded animals in the tropical and subtropical regions of the New World. Its known normal distribution extends from Argentina, South America, to the southern part of the United States; it has been found in a few instances in several of the more

northern States. The earliest authentic record of its occurrence in the United States dates back to 1882.

The activity of the adults of *Cochliomyia americana* is considerably influenced by seasonal variations in temperature. In the southern part of the United States, the fly begins its attacks late in the spring or early in the summer. As a rule, the first killing frosts in the fall mark the cessation of the fly's activity throughout the winter; during the milder winters, however, temperatures are not low enough to kill the adults.

Studies on the duration of the different stages of *Cochliomyia americana* reveal the following facts: (1) The incubation period of eggs on wounds in animals ranges from 11 to 21.5 hours under natural conditions; in one instance, in an animal in a laboratory, eggs hatched in 6 hours, and under controlled conditions of temperature and 100 percent relative humidity the incubation period ranged from 9.2 hours at 99° F. to 13.9 hours at 84°; no hatching takes place at 59°. (2) The duration of all larval instars in cattle infested in nature ranges from 82 to 239 hours; in sheep the weighted mean range of this stage was from 103.8 to 174.5 hours. The length of the different instars appears to be influenced by the size of the wound and the number of larvae that infest it. (3) The prepupal stage lasts from 7 to 76 hours and the pupal stage from about 7 days in the summer to 54 days during the winter. The duration of both these stages is considerably influenced by temperature and moisture. (4) The longevity of adults in captivity is usually short (about 7 to 30 days), but in one instance a female lived 65 days.

Eggs, larvae, and adults of *Cochliomyia americana* can be distinguished from those of *C. macellaria;* the eggs, by the wider band which encircles the micropyle; the larvae, by differences in the structure of the cephalopharyngeal mechanism, the size and arrangement of spines on the segments, the posterior spiracles, and the size of the tubercles on the last segment; the adults, by the form of the genitalia and differences in coloration of certain parts of the body.

Larvae of *Cochliomyia americana* appear to penetrate more deeply into soil to pupate than do those of *C. macellaria.*

Individual females of *Cochliomyia americana* may lay as many as 2,853 eggs. The eggs are deposited in characteristic batches of 10 to 393 eggs each, and the oviposition of as many as 300 eggs may be completed in from 4 to 6 minutes.

Eggs of *Cochliomyia americana* are killed at temperatures near the freezing point, but prepupae, pupae, and adults are able to withstand temperatures considerably below this point.

The evidence indicates that under natural conditions *Cochliomyia americana* breeds only in live animals, but in the laboratory it has been possible to rear it from the egg to the adult stage on dead tissue.

The comparative abundance of *Cochliomyia americana* and *C. macellaria* in nature, as determined by the number of each species attracted to fresh and necrotic wounds, is 1 of the former to 590 of the latter; as determined by the number taken in meat-baited flytraps, the ratio is 1 to 2,427.

Under controlled laboratory conditions the length of the life cycle of *Cochliomyia americana* is about twice that of *C. macellaria.*

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THE CANNIBALISTIC HABITS OF THE CORN EAR WORM

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INTRODUCTION

For many years it has been known that the larvae of the corn ear worm (*Heliothis obsoleta* Fab.) are cannibalistic, under certain conditions killing and devouring fellow larvae, especially when competing for food. This habit makes possible the raising of corn over extensive sections where the corn ear worm is prevalent, for it is probable that, were the larvae tolerant of each other when feeding in close association, the original populations that annually attack cornfields could easily destroy the entire crop. In order to learn more about the cannibalistic habits of these larvae, a detailed study was made at Richmond, Va., in 1929, and at Savannah, Ga., during the years 1930 to 1932, inclusive.

EAR WORM INJURY TO THE CORN PLANT

During the several months that the corn plant is growing, its suitability as food for the corn ear worm varies. Although the larvae attack the leaves, tassels, husks, and cobs, particularly while these parts are young and tender, by far the largest populations are found on the silks and kernels, which consequently suffer the greatest injury.

The plant is most attractive to ear worm moths for egg laying while the silks of the developing ears are fresh, and usually more eggs are laid on such silks than on all the other parts of the plant. During the several weeks that the silks are moist, eggs are laid on them every

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night, the number depending on weather conditions, the variety of corn, and the abundance of the moths. In the Southern States hundreds of eggs may be deposited on the silks of a single ear. Larvae hatching from these eggs immediately seek the husk-enclosed portions of the silks and begin to feed. As a result they become concentrated in one part of the plant, in an environment that affords food sufficient for the nourishment of many larvae but is limited in area according to the stage of development of the surrounding husk.

After feeding downward in the husk-enclosed silk, the larvae eventually reach the kernels, which serve as the final larval food. Although many eggs are destroyed by insect enemies and otherwise, scores often hatch and the young larvae enter the ear frequently in populations potentially able to consume the entire ear. Yet, notwithstanding the large numbers of young larvae that enter the ear, few become full grown, and it is most common to find that only one larva has reached maturity in an ear, the others presumably having been destroyed.

DECREASE IN EAR WORM POPULATIONS THROUGH CANNIBALISM

To determine to what extent the ear worm populations of ear corn decrease as the larvae become full grown, ears from infested fields were examined and, as a check on the results obtained, caged larvae were studied. The experiments with the caged larvae were conducted under comparable conditions, but in the experiments with ears from infested fields variation in age, size, and husk characters could not be avoided.

IN EAR CORN IN THE FIELD

OBSERVATIONS AT RICHMOND

A 10-acre field of yellow dent corn at Richmond, Va., was selected in the fall of 1929 as suitable for observation because of uniformity in soil, plant growth, and distribution of the ear worm infestation. One thousand ears from this field were examined for infestation during the period September 23 to 25. At that time the ears were in the dough stage, larval activity was at its height, relatively few individuals had become full grown and deserted the ears, and all larval instars were represented. All the ears contained larvae, either in the silk or on the ear, and many of the larvae were being devoured by others. The number of larvae of each instar and the prevalence of partly devoured individuals are shown in table 1.

TABLE 1.—*Corn ear worm larvae of the different instars recovered from 1,000 ears of yellow dent field corn and prevalence of partly eaten individuals, Richmond, Va., 1929*

Instar	Larvae recovered		Larvae partly devoured		Larvae recovered that were partly devoured
	Number	*Percent*	*Number*	*Percent*	*Percent*
First	24	0.72	0	0.00	0.00
Second	340	10.16	1	.47	.29
Third	1,049	31.33	30	14.08	2.86
Fourth	902	26.94	84	39.43	9.31
Fifth	660	19.71	93	43.67	14.09
Sixth	373	11.14	5	2.35	1.34
Total, or weighted average	3,348		213		6.36

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Partly devoured individuals were found in 192 ears. Of these ears 172 contained 1 partly devoured larva each, 19 ears contained 2 larvae each, and 1 ear contained 3 larvae. At the time of observation 6.36 percent of the recovered larvae had been partly devoured. Since larvae feed within the ears for several weeks, a continuous thinning of population, at the rate indicated at this examination, could easily account for the large reduction in numbers that has been observed to occur in nature. These and many other observations indicate that ear worm larvae usually devour other ear worm larvae that they attack; that is, they seldom leave killed individuals uneaten.

It was found that larval populations ranged from 1 to 10 per ear. Ears infested by large larvae contained fewer individuals than did ears infested by small larvae. Examination of these ears while the silks were moist and eggs were being deposited on them showed daily egg populations ranging from 5 to 25 each, and oviposition continued as long as the silks remained moist.

In table 2 the data on larval infestation of ears have been classified according to the number of larvae present and also according to the instar of the largest larva recovered in each ear. These data indicate a gradual thinning of larval populations from the time fourth-instar larvae began to appear, but they do not show the final extent of cannibalistic thinning of populations, as the larvae would have had to feed for different periods of time before completing their development. Figure 1 shows four ears, selected at random, containing larvae of various sizes, and indicates the decrease in population with increase in size of the larvae.

TABLE 2.—*Population of ear worm larvae of different instars in 992 ears of corn at roasting-ear stage, Richmond, Va., Sept. 23–25, 1929*

Larvae recovered per ear (number)	Number and percentage of ears in which the largest larva was in the instar indicated [1]								Total ears
	Third		Fourth		Fifth		Sixth		
	Number	*Percent*	*Number*	*Percent*	*Number*	*Percent*	*Number*	*Percent*	*Number*
1	5	6.09	3	1.42	41	11.33	110	32.74	159
2	4	4.88	22	10.38	87	24.04	116	34.52	229
3	16	19.51	38	17.92	103	28.45	65	19.35	222
4	27	32.93	50	23.59	64	17.68	33	9.83	174
5	15	18.29	46	21.69	37	10.22	6	1.79	104
6	9	10.98	28	13.21	17	4.69	4	1.19	58
7	5	6.09	11	5.19	8	2.21	1	.29	25
8	1	1.22	12	5.66	2	.55	1	.29	16
9			1	.47	3	.83			4
10			1	.47					1
Total ears	82		212		362		336		992
Total larvae	341		951		1,166		738		3,196
Average larvae per ear	4.16		4.49		3.22		2.20		3.22

[1] Ears with only first- or second-instar larvae were too few for tabulation.

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OBSERVATIONS AT SAVANNAH

During 1931 and 1932 the study was continued at Savannah, Ga., where ears of corn at roasting-ear stage were examined for larval populations. This corn had been planted at varying intervals over a period of 3 to 4 months. Ears and silks were therefore exposed to oviposition over a rather long period and presumably received varying numbers of eggs, depending on the number of moths present in

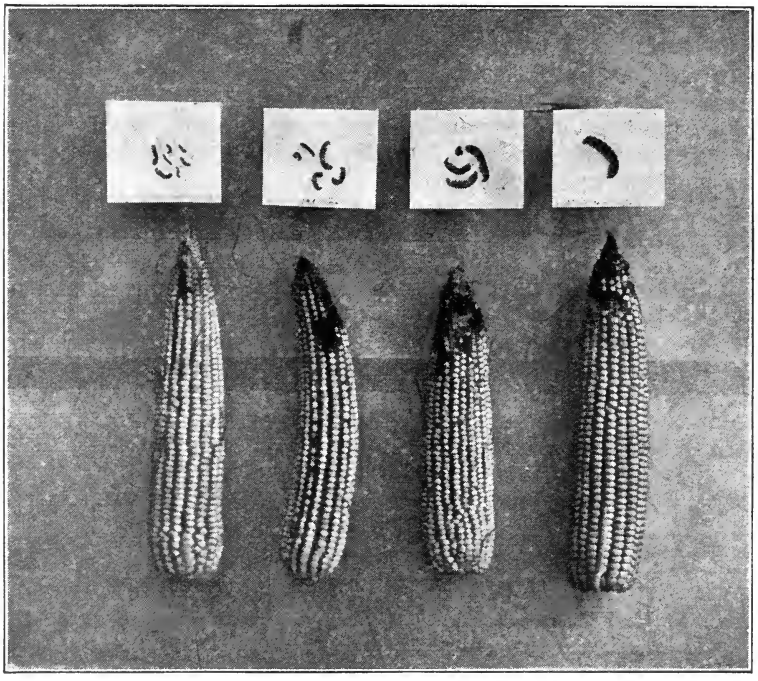

FIGURE 1.—Ears of corn and the populations of corn ear worm larvae they contained, illustrating the decrease in larval population from cannibalism as larvae increase in size.

the field. The data were classified according to the instar of the largest larva present in each ear; and the average larval populations, as well as the number of larvae in each instar, were determined for each class. The data obtained from 392 infested ears in 1931, and from 1,510 infested ears in 1932, are summarized in table 3. Here again ears that contained the larger larvae had considerably smaller populations than ears containing smaller larvae.

TABLE 3.—*Number of ear worm larvae of different instars inhabiting corn ears at roasting-ear stage, Savannah, Ga., 1931 and 1932*

Larvae recovered	Number of ears in which the largest larva was in the instar indicated										
	From plantings examined June 8 to Aug. 6, 1931					From plantings examined June 5 to Aug. 30, 1932					
	Third	Fourth	Fifth	Sixth	Full grown[1]	Second	Third	Fourth	Fifth	Sixth	Full grown
Per ear:											
1	2	28	55	74	111	6	49	112	271	241	249
2	1	8	26	28	13	2	26	48	108	85	72
3	2	2	13	8	5	2	14	32	55	21	22
4	------	1	7	------	0	1	1	15	27	8	7
5	------	------	2	2	1	------	3	7	11	4	------
6	------	------	2	1	------	------	1	1	4	------	------
7	------	------	------	------	------	------	------	1	------	------	------
8	------	------	------	------	------	------	------	------	1	------	------
9	------	------	------	------	------	------	------	------	------	------	------
10	------	------	------	------	------	------	------	------	------	1	------
11	------	------	------	------	------	------	------	------	1	------	------
Total	5	39	105	113	130	11	94	216	478	360	350
	Number of larvae found of which the largest larva was in the instar indicated above										
In all ears:											
First instar	0	0	0	0	4	4	0	1	1	0	0
Second instar	2	0	6	2	0	16	38	35	29	6	0
Third instar	8	8	13	2	0	------	130	103	100	35	15
Fourth instar	------	46	50	14	3	------	------	273	174	49	36
Fifth instar	------	------	127	32	10	------	------	------	554	67	56
Sixth instar	------	------	------	120	8	------	------	------	------	379	14
Full grown	------	------	------	------	132	------	------	------	------	------	366
Total	10	54	196	170	157	20	164	412	858	536	487
Average per ear	2.00	1.38	1.87	1.50	1.21	1.82	1.78	1.91	1.79	1.49	1.39

[1] Larvae that had already left the ear.

STUDIES OF LARVAE IN EXPERIMENTAL CAGES

The decrease in larval populations through cannibalism was studied under controlled conditions in the laboratory. Ten series each of 5, 10, 15, 25, and 50 newly hatched larvae were confined in 2-ounce tin salve boxes, 60 mm in diameter and 20 mm in height, a type of cage that had previously been used successfully in studying larvae of this species and which provided conditions as close as possible to those in the field. These larvae were given as food equal quantities of moist silks and corn kernels in the dough stage, and every day the rate of growth and the number of individuals present were recorded.

Not more than one larva became full grown and pupated in any of the 50 cages. Not only were the other larvae in the cage killed, but they were usually completely devoured. Therefore, each full-grown individual had been nourished with plant and animal food in varying proportions. It is probable that many of the larvae devoured had, themselves, devoured other larvae, thus making the elimination of larvae a successive matter; that is to say, each larva that finally survived had fed upon others, which had fed upon others, and so on, depending upon the number of larvae in the cage. Although the larvae were well supplied with vegetable food at all times, in none of

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the cages had this food been wholly consumed, and the larvae were not confined nearly so closely as they would have been in the husk-enclosed silks and kernels of an ear of corn.

Curves showing population decreases, as determined in these experiments, are given in figure 2, each curve representing the average

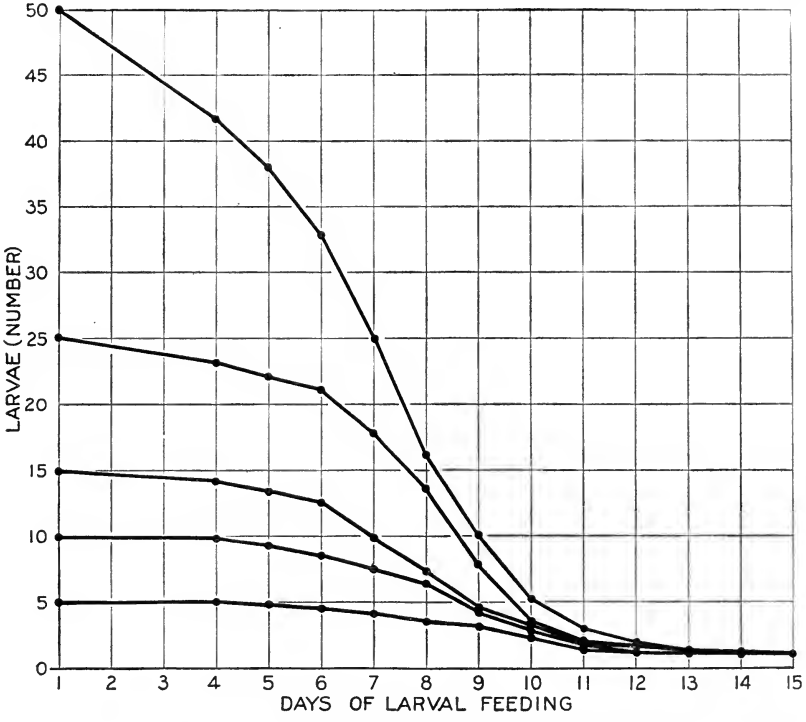

FIGURE 2.—Decrease in population of corn earn worm larvae confined in salve-box cages during feeding period.

for the 10 cages having the same number of larvae per cage. It was shown that in large populations cannibalism was displayed throughout the feeding period, whereas in smaller populations it was not manifest until the sixth day, or when the larvae had reached the third instar. In table 4 the numbers and percentages of larvae reaching the several stages of growth in these experiments are given.

TABLE 4.—*Corn ear worm larvae surviving to the different instars in various population concentrations in breeding cages*

Larvae introduced per cage (number)	Total larvae used	Larvae surviving to instar indicated										Full-grown larvae surviving
		Second		Third		Fourth		Fifth		Sixth		
	No.	*No.*	*Pct.*	*No.*	*Pct.*	*No.*	*Pct.*	*No.*	*Pct.*	*No.*	*Pct.*	*No.*
50	500	412	82.4	325	65.0	140	28.0	36	7.2	12	2.4	1
25	250	230	92.0	193	77.2	130	52.0	43	17.2	12	4.8	1
15	150	142	94.7	119	79.3	67	44.7	26	17.3	11	7.3	1
10	100	96	96.0	84	84.0	54	54.0	38	38.0	17	17.0	1
5	50	50	100.0	44	88.0	37	74.0	23	46.0	12	24.0	1

RELATION BETWEEN AGE OF LARVAE AND CANNIBALISTIC TENDENCY

Both the field and the laboratory experiments indicate that cannibalism increases in intensity with the age of the larvae. To study this factor further, varying populations of larvae of similar and of different instars were confined in salve-box cages to determine how quickly such populations would be reduced to a single individual.

This experiment, which is briefly summarized in table 5, shows that the larger larvae are the most intensely cannibalistic. Ear worm larvae usually complete their feeding in the first ears of corn they enter. They do not seek out fellow larvae as prey, but simply attack and devour those they meet in the course of burrowing and feeding through the silks or kernels. Since the feeding quarters are limited, the larger larvae are much more likely to meet while feeding than are the smaller ones. The chances of meeting appear to be proportional to the size of the larvae and the number in individual ears. Of the individuals that were supplied only with fellow larvae as food, the larger larvae—those in the fourth, fifth, and sixth instars—fed more readily and were much more easily reared to maturity than were the smaller ones.

TABLE 5.—*Cannibalism of ear worm larvae of the same and of different instars when confined in varying numbers in salve-box cages*

Instar of larvae	Cages	Larvae per cage	Average time before population was reduced to one larva per cage	Instar of larvae	Cages	Larvae per cage	Average time before population was reduced to one larva per cage
Larvae of the same instar:	*Number*	*Number*	*Days*	Larvae in different instars: [1]	*Number*	*Number*	*Days*
First	6	3 to 25	12.2	Second	1	10	8.0
Second	2	10	8.5	Third	5	6 to 19	4.4
Third	6	2 to 5	3.2	Fourth	9	3 to 26	3.4
Fourth	10	2 to 5	3.2	Fifth	6	4 to 19	3.5
Fifth	12	4 to 5	2.7	Sixth	13	4 to 14	1.9
Sixth	8	2 to 3	1.7				

[1] The instars given in this series refer to the instar of the largest larva in the cage.

FOOD PREFERENCES OF LARVAE FOR CORN PLANT OR FELLOW LARVAE

Various reasons have been given for the habit of cannibalism among ear worm larvae. Plant food may have been insufficient or competing larvae may have interfered with one another's normal feeding, either cause leading to combat between larvae and finally to the devouring of the vanquished by the victor. A study of cannibalism was made, therefore, under conditions in which no competition existed and food was abundant. Larvae of various instars were confined singly in salve boxes containing an abundant supply of fresh corn silks and fresh kernels in the dough stage, and such food was renewed daily. In addition, a freshly maimed larva of the same or the preceding or following instar was placed in each cage every day. These larvae were maimed by crushing their heads, which rendered them inactive and unable to compete for food.

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The feeding was observed to vary. On some days the larvae fed only on plant material, on other days on both the plant material and the maimed larvae, and rarely on only the maimed larvae. It was found that second-instar larvae fed only on plant material about as frequently as on both fellow larvae and plant material, whereas larger larvae more often consumed both animal and vegetable food, the likelihood of such mixed feeding increasing in proportion to the size of the larvae. Fifth-instar larvae selected a mixed ration nearly four times as often as one of plant food only. Larvae rarely fed entirely on their fellow larvae when an abundance of plant food was available. Nevertheless, they often chose the maimed larvae as food when they had no competitors and were abundantly supplied with their preferred plant food, although there was no indication that they actually searched for the animal food. The results of these experiments are given in table 6.

TABLE 6.—*Food preference of corn ear worm larvae when offered maimed ear worm larvae together with fresh corn silks and kernels in the dough stage*

Instar of larvae	Larvae observed	Larvae feeding on—					
		Corn silks or kernels only		Corn silks or kernels and maimed larvae		Maimed larvae only	
	Number	*Number*	*Percent*	*Number*	*Percent*	*Number*	*Percent*
Second	51	25	49.0	24	47.1	2	3.9
Third	37	16	43.2	20	54.1	1	2.7
Fourth	70	26	37.1	41	58.6	3	4.3
Fifth	63	13	20.6	48	76.2	2	3.2
Sixth	53	18	33.9	33	62.3	2	3.8

DEVELOPMENT OF LARVAE WHEN FED FELLOW LARVAE EXCLUSIVELY

The degree to which the cannibalistic habit of ear worm larvae is fixed is demonstrated in their ability to develop to maturity from any larval instar exclusively as predators, entirely without plant food. When individuals were reared from egg to adult in this way, they were as large as ear worms ever become when feeding on their preferred food, and they were of the usual vigor. To rear ear worms successfully in this way, care must be taken to keep fresh food before them at all times. The feeding larvae were confined singly in salve boxes lined with absorbent paper, and were fed maimed larvae of the same or the succeeding instar. Although many of the maimed larvae lived more than 24 hours, decomposition of the crushed parts was often noticeable in from 6 to 8 hours, and this rendered the larvae unfit for food, as individuals that fed upon such decomposing matter died before reaching maturity. Through artificial control of bacteria in the laboratory, nearly perfect rearings of these predacious larvae could no doubt be made.

Larvae of each instar were taken from corn ears in which they had fed normally and were reared to adults by the method described. In addition, ear worm eggs were taken from oviposition cages and confined in lots of 10 in concave cells ground in microscope slides, covered with plain slides. In each lot the population of larvae that hatched from the eggs was usually reduced to a single individual within a few

days through cannibalism. The surviving individuals were reared singly in vials or salve boxes wholly upon maimed larvae, as previously described. In one series of 16 larvae, 12, or 75 percent, of the individuals became full-grown larvae; 9, or 56.3 percent, pupated; and 7, or 43.8 percent, developed into healthy and active moths.

The voracity with which ear worms attack their fellow larvae when given the latter as food reminds one of the more ruthless, solely predacious insects. The ear worm larvae usually attacked the ventral surface of the abdomen of its prey. One bite penetrated the exoskeleton; then the feeder plunged its mouth parts into the blood and internal structures thus exposed and fed eagerly. When a small larva attacked a larger one, it often curved its body laterally about its prey, holding on tenaciously while the latter tried to dislodge it. In many instances after a few hours all that remained of a maimed larva was the empty head capsule, the exoskeleton of which was apparently too hard to be eaten by the predator.

Larvae of the corn ear worm, when feeding upon unprotected vegetation, such as the exposed seeds of *Meibomia purpurea*, protect themselves from parasites, other small insects, and fellow larvae by a method practiced by many lepidopterous larvae. When the larva is touched on any part of its body, it instantly stops feeding and, with its mouth parts in readiness for biting, makes a quick lunge in the direction of the attack, often regurgitating a drop of liquid at the same time. It then draws back its head and remains motionless, ready to strike again. Two antagonistic larvae of equal size, in such a pose of alert preparedness, are an interesting sight, and if they could snarl or growl or hiss the spectacle of ferocity thus presented would be complete. In ear corn, however, such free fighting is impossible, because the larvae cannot move freely, and the advantage is with the larva that makes contact with the unprotected parts of another which, because of cramped quarters, cannot protect itself.

The time required for the development of wholly predacious ear worm larvae, as compared with that for individuals fed upon corn silks and kernels, is shown in table 7. The former required an average of about 3 weeks, the latter about 2 weeks.

TABLE 7.—*Period of larval development of the corn ear worm when fed only on maimed ear worm larvae, and when fed only on silks and corn kernels, at Savannah, Ga., 1930*

Larval food	Hatching date	Individuals	Average time in each larval instar						Average larval period
			First	Second	Third	Fourth	Fifth	Sixth	
		Number	*Days*	*Days*	*Days*	*Days*	*Days*	*Days*	*Days*
Larvae	July 9–27	44	4.33	2.53	2.36	2.80	3.67	3.86	18.55
	Aug. 13–18	25	5.32	3.84	2.92	2.65	4.05	4.67	22.90
Corn silks and kernels	July 18	25	4.12	2.08	1.76	1.64	1.68	2.82	14.16
	Sept. 2	50	2.16	2.30	1.92	2.20	[1] 3.79	-------	[1] 12.75
							[2] 2.71	[2] 3.00	[2] 13.59

[1] Larvae of 5 instars. [2] Larvae of 6 instars.

The total number of fellow larvae devoured by wholly predacious ear worm larvae while completing their development varied, as did also

the rate of consumption of such food in any one instar. When a predator larva fed on maimed larvae of the same instar, the total number of fellow larvae consumed by the surviving predator during its entire larval period was about 20, and relatively the largest quantities of food were consumed during the first and last instars. The last-instar larva usually consumed 1 fellow larva of its own size each day, but sometimes it completely devoured 2. When a large predacious larva was fed smaller larvae, the total number of individuals devoured was naturally much greater. The numbers and instars of fellow larvae devoured by 25 individuals while in the last 3 instars are given in table 8. These studies indicate that in times of heavy infestation the consumption of larvae by fellow larvae occurs at a rate sufficient to account for the destruction of scores, or even hundreds, of larvae by successive elimination during a period of several days or weeks.

TABLE 8.—*Number of maimed corn ear worm larvae devoured by individuals of the same species in their last three instars, Savannah, Ga., 1930*

Instar in which larva began cannibalistic feeding [1]	Date feeding began	Date larvae became full grown	Number of larvae of instars indicated devoured by individuals in—								
			Fourth instar		Fifth instar				Sixth instar		
			Fourth	Fifth	Third	Fourth	Fifth	Sixth	Fourth	Fifth	Sixth
Third	July 11	July 25	2				3.0				5.5
	July 12	[2]	2	0.5							
	do	July 26		2.0				2.5			6.0
	July 16	July 30	2	.5			3.0	1.0		2	5.0
	do	July 27	1				2.0	.5		2	3.0
Fourth	July 9	[2]					2.0	1.0		2	3.0
	do	July 17					2.0			1	3.0
	do	[2]				1	2.0				
	do	[2]					2.5				
	July 12	July 25					3.0	1.0			6.0
	do	July 23				1	2.0			2	4.0
	July 16	July 27				1	1.0	1.0		1	4.0
Fifth	July 9	July 19			1	1	1.0			2	3.0
	do	July 16									4.0
	July 11	do							3	2	2.0
	do	do								1	4.0
	do	July 15								2.5	2.0
	July 16	July 27					2.0	1.0			5.0
Sixth	July 24	July 29									4.0
	do	do									4.0
	do	July 26									3.0
	July 27	July 30								1	4.0
	do	July 29									4.0
	do	July 30								1	4.0
	do	July 29								1	2.0

[1] 1 larva in each cage.

[2] Larva did not mature.

RELATION BETWEEN CORN-HUSK TYPE AND CANNIBALISM OF THE EAR WORM

The growing ears of different varieties of corn, or even ears of the same variety, differ greatly in the character of their husks. The husks may be nearly lacking, as in tassel ears (fig. 3); they may not be long enough to envelop the ear completely (fig. 4); they may be just long enough to enclose completely and tightly envelop the ear (fig. 5); they may be extended far beyond the tip of the ear (fig. 6); or they may occur in all intermediate lengths. The husks also vary

in the number of leaves of which they are composed and in the tightness with which these leaves are wrapped about the ear, the latter characteristic depending somewhat upon the stage of growth of the grain. The factors enumerated determine the feeding areas attainable by ear worm larvae, the comparative ease with which the several parts are reached, and the degree of competition among the larvae in their quest for food.

The habit of ear worm larvae of seeking protected places for feeding is important in this connection. It was found that when the husks were partly removed, exposing the upper half or a longitudinal strip

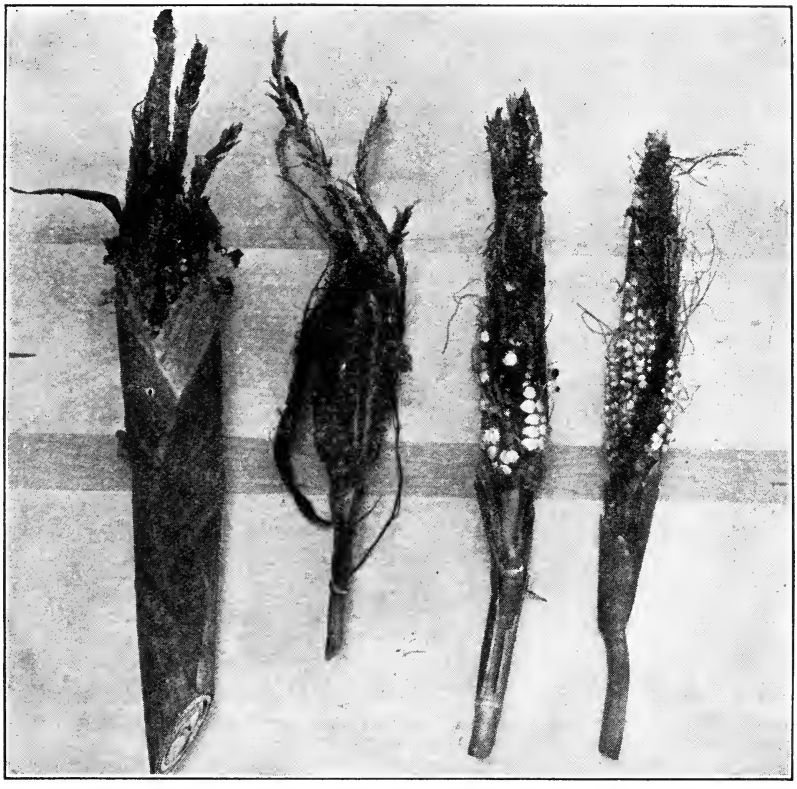

FIGURE 3.—Tassel ears of corn, with loose, poorly developed husks, which favor the feeding of larvae on all parts of the ear.

of the cob and kernels, the feeding was usually confined to the part of the ear that was still protected by the husks. This evident desire for protection leads to concentration of larval population in parts of the ear that can be penetrated, and the degree of such concentration depends upon the type of husk and upon the original population of larvae. The ear is seldom penetrated except at the tip, where the silk is exposed.

The nature of the husk determines the chance that the larvae will meet one another. In ears such as are shown in figure 3 larvae can enter on all sides, seek shelter behind the loose husks, and feed unmo-

lested on the different parts of the ear, with little chance of meeting other larvae. On the other hand, in ears such as are shown in figure 6 the larvae can enter only at the point of extrusion of the silks, and they must feed on the tightly wrapped silks in a tubelike passage before they can reach the kernels. In such ears the individuals, being more narrowly confined, are far more likely to meet one another and reduce the population through cannibalism. The degree of cannibalistic feeding in the ears with husk type between these two extremes varies accordingly.

Previous work concerned with the economic value of the husk in limiting ear worm injury to ear corn bears out these statements.[1] Study of many thousand ears of corn, both in the field and in the laboratory, showed important differences in grain losses that de-

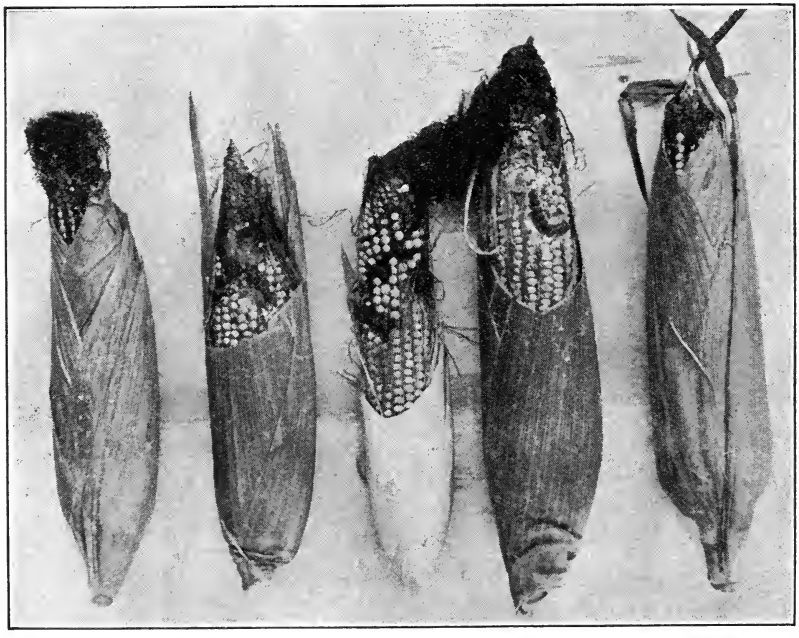

FIGURE 4.—Corn ears with short, loose husks, which allow ear worm larvae to feed on all sides of the ear with little competition.

pended on the character of the husk, because this greatly influenced the number of larvae that successfully fed on the ear. The condition can easily be observed in most cornfields, although, of course, the final results of cannibalism cannot be determined until the larvae have completed feeding.

Five hundred and nineteen of the ears from which the data given in table 2 were taken were classified according to husk length, and the position occupied by the feeding larvae in these ears was observed. The data obtained are given in table 9. Much variation was found in the positions occupied by the larvae. In general, as the length of the husk beyond the tip of the ear increased, fewer larvae were

[1] PHILLIPS, W. J., and BARBER, G. W. THE VALUE OF HUSK PROTECTION TO CORN EARS IN LIMITING CORN EAR WORM INJURY. Va. Agr. Expt. Sta. Tech. Bull. 43, 24 pp., illus. 1931.

found feeding on the kernels and more were found in the silks. Furthermore, the average numbers of larvae found in these ears decreased

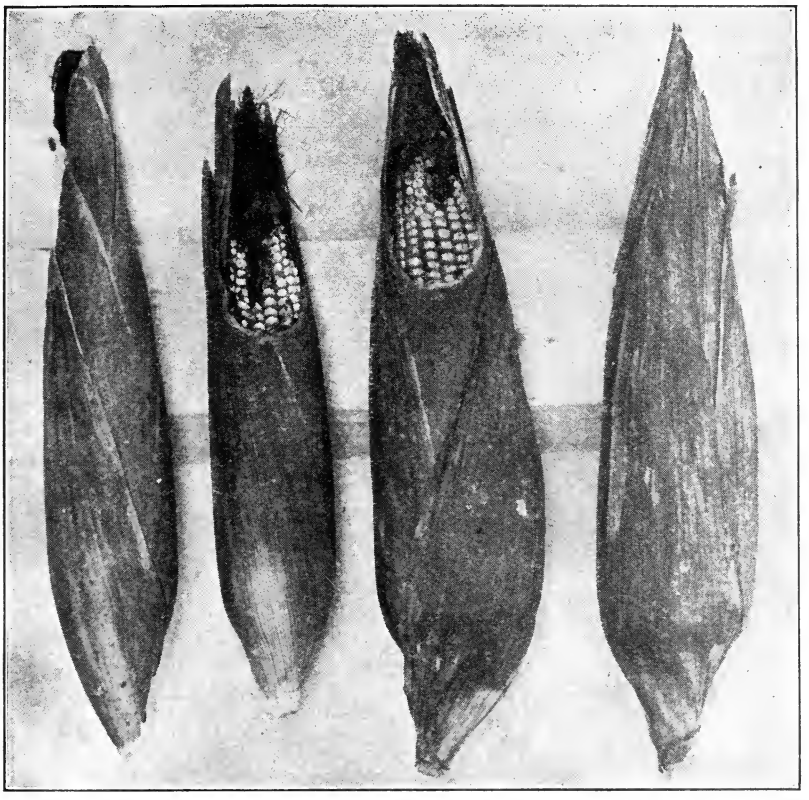

FIGURE 5.—Corn ears with husks long enough to enclose completely and tightly envelop the ear, with little injury by ear worms because cannibalism is developed through competition in feeding.

as the length of the husk increased, suggesting a proportional increase in the degree of cannibalism. This condition is shown graphically in figure 7.

TABLE 9.—*Number of ear worm larvae recovered in the silks and on the kernels of ears of corn with husks of various lengths, at Richmond, Va., 1929*

Length of husk beyond tip of ear (inches)	Ears		Average larvae per ear in instar indicated										Average larvae of all instars per ear			Larval population recovered	
			On the kernels					In the silks									
			Second	Third	Fourth	Fifth	Sixth	First	Second	Third	Fourth	Fifth	Sixth	On kernels	In silk	Total	On kernels	In silk
	No.	*Pct.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*Pct.*	*Pct.*
0.0 [1]	66	13.2	0.15	0.67	1.12	0.89	0.65	----	0.03	0.05	0.01	----	----	3.48	0.09	3.57	97.48	2.52
0.1 to 1.0	139	27.8	.16	.80	.89	.66	.36	----	.21	.65	.22	0.05	----	2.87	1.13	4.00	71.75	28.25
1.1 to 2.0	122	24.4	.09	.50	.47	.39	.35	0.008	.25	.84	.40	.15	0.03	1.80	1.69	3.49	51.59	48.41
2.1 to 3.0	94	18.8	.03	.21	.39	.35	.29	.01	.29	.83	.42	.22	.05	1.27	1.82	3.09	41.10	58.90
3.1 to 4.0	45	9.0	----	.07	.29	.31	.20	----	.20	.78	.56	.31	.11	.87	1.96	2.83	30.74	69.26
4.1 to 5.0	38	3.8	----	.16	----	.21	----	----	.42	1.32	.47	.42	.05	.37	2.68	3.05	12.13	87.87
5.1 to 9.0	15	3.0	----	.07	.07	.33	.20	----	----	.47	.33	.40	.20	.67	1.40	2.07	32.37	67.63

[1] Tip of ear exposed.

The relation between corn-husk type and cannibalism of ear worms was also studied under conditions in which the number of larvae entering the corn ears could be controlled. Twenty-four uninfested ears with husks ranging from very short to very long were selected. In 12 of these ears the husk was loosened to allow the larvae easier entrance, but in the other 12 ears the husk was not disturbed. Each ear was placed in an upright position in a cylindrical box upon a

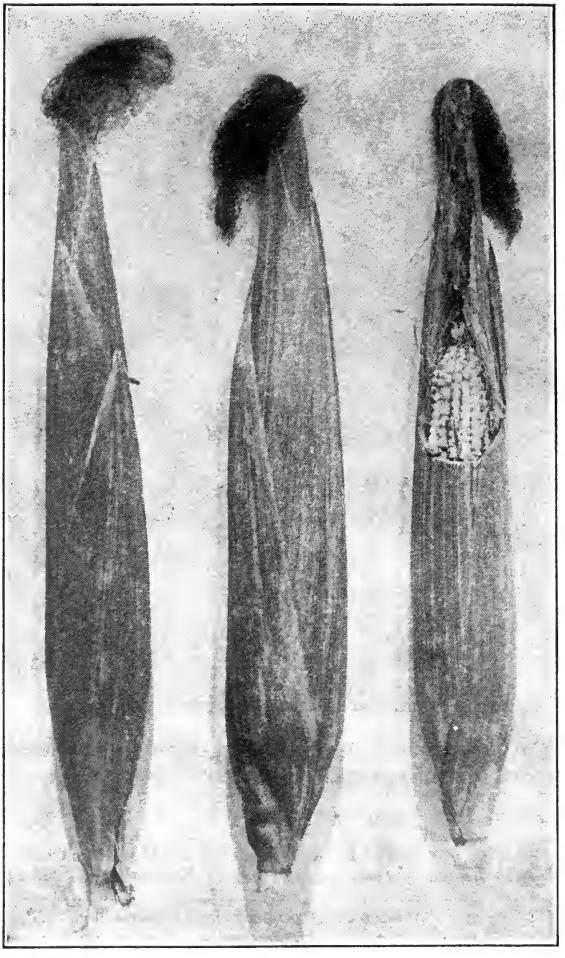

FIGURE 6.—Corn ears having long, tight husks, with practically no grain injury, and where cannibalism by ear worms can be intensely developed.

nail driven through the bottom, so that no part of the ear touched the side of the box. Each ear in both series was then artificially infested with 10 newly hatched ear worm larvae. No other larvae were allowed to enter or leave these cages. At the end of 10 days the cages were examined, and larvae were still feeding, most of them being in the fourth or fifth instar. There was considerable difference in the extent of injury to the kernels, and also in the degree of larval survival, between the ears protected by tight husks and those in

which the husks had been loosened. The 12 ears with tight husks showed a total of 337 injured kernels, representing a grain loss of 4.3 percent, and 34 of the original 120 larvae remained, an average of 2.8 larvae per ear. In the 12 ears with the loosened husks there were 776 injured kernels, or a grain loss of 11.87 percent, and 56 of the original 120 larvae remained, an average of 4.7 per ear.

A third series of 12 uninfested ears, as nearly alike as possible, were artificially infested with newly hatched larvae in the same manner as before. Before being placed in the cages, however, the husks of 4 ears were loosened about the kernels, those of 4 others were removed on half of each ear, and the husks of the 4 remaining ears were left undisturbed. One ear of each group was infested with 10 larvae, one with 20, one with 30, and one with 40. When the ears were examined, after 18 days, larvae were still feeding, being in the fifth or sixth instar.

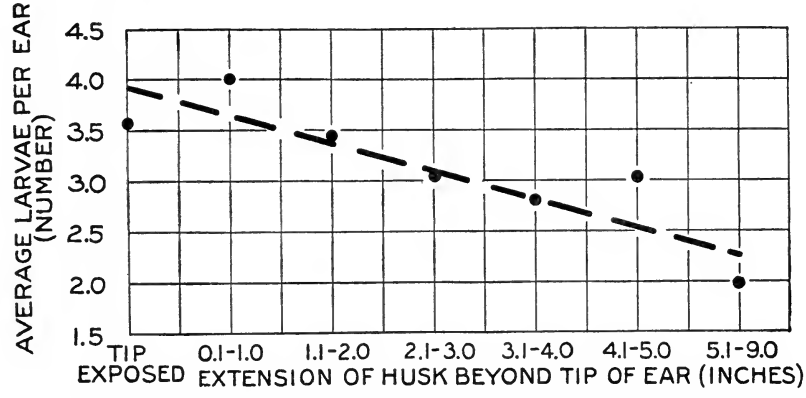

FIGURE 7.—Populations of ear worm larvae recovered in ear corn having husks of various lengths, showing the relation of husk character to cannibalism of the larvae.

There were notable differences in the extent of kernel injury and in the degree of larval survival, depending on the protection afforded by the husks. The results of this series of experiments are shown in table 10.

TABLE 10.—*Injury to kernels and survival of corn ear worm larvae in artificially infested ears of corn originally similar but with the husks loosened, partly cut away, or undisturbed, Richmond, Va., 1929*

Larvae introduced per ear (number)	Husks loosened about ear			Husks cut away on half of ear			Husks undisturbed		
	Kernels injured		Larvae recovered	Kernels injured		Larvae recovered	Kernels injured		Larvae recovered
	Number	*Percent*	*Number*	*Percent*	*Number*	*Number*	*Number*	*Percent*	*Number*
10	147	22.83	3	50	8.17	2	35	6.08	1
20	234	30.49	5	118	20.49	4	85	13.12	3
30	292	40.89	4	221	32.22	7	101	13.15	2
40	391	66.49	7	364	56.52	7	122	21.63	3
Total			19			20			9
Average		39.20	4.8		29.90	5.0		13.42	2.3

The results of all these experiments in which the original number of larvae was controlled indicate that the type of husk is an important factor influencing the extent of cannibalistic feeding by ear worm larvae in corn ears. Loose husks through which the tip of the ear extends unprotected permit larvae to enter the ear at all sides and to feed at all points upon the grain, and this reduces their chance of meeting one another. On the other hand, ears having long husks tightly wrapped about the ears and the silks present but a single point of attack, where the silk is exposed, and this condition affords the most favorable opportunity for cannibalism. Such feeding quarters are also more favorable to cannibalism than are afforded by any other part of the corn plant.

EXTENT OF CANNIBALISM AS RELATED TO GRAIN LOSSES

Concerning the relation between cannibalism and grain losses, the results obtained in a previous study of injury to more than 50,000 corn ears, representing numerous varieties grown in different years, and in different localities, have been given in an earlier paper.[2] In this bulletin only additional evidence obtained from artificially infested ears, where the ear worm populations were definitely known, is introduced. Extreme types of ears were used, and the husks were in some instances loosened. The injury caused by ear worm larvae to the kernels of the ears is summarized in table 11. In the ears having the most poorly developed husks an average destruction of 52.77 percent of the kernels was recorded, whereas in those ears having husks extending 3 inches or more beyond the cob, and closely wrapped about the entire ear, only 1.53 percent of the kernels were injured. It was observed that the length and the tightness of the husks were both of importance in protecting the ears from injury.

TABLE 11.—*Injury to kernels on ears having various types of husk protection and artificially infested with known numbers of ear worm larvae*

Husk protection of ears	Ears	Total larvae introduced	Average larvae per ear	Average period of observation	Average kernels per ear prior to attack	Average kernels injured per ear	
	Number	*Number*	*Number*	*Days*	*Number*	*Number*	*Percent*
Tassel ears, husks poorly developed	6	68	11.3	10.3	433.0	228.5	52.77
Tip of ears exposed, protection poor:							
Husk tight	13	109	8.4	12.9	854.7	116.4	13.62
Husk loosened	10	90	9.0	11.0	892.0	184.4	20.67
Husk loose in general:							
Short: [1]							
Husk tight	3	30	10.0	13.7	953.0	216.5	22.72
Husk loosened	9	90	10.0	12.4	971.1	227.7	23.46
Medium: [2]							
Husk tight	9	72	8.0	12.0	912.6	110.3	12.09
Husk loosened	8	76	9.5	12.1	751.3	109.8	14.61
Long: [3]							
Husk tight	16	177	11.1	11.3	859.5	67.9	7.90
Husk loosened	6	60	10.0	12.3	539.7	80.5	14.92
Husk tight in general:							
Short,[1] husk tight	14	166	11.9	11.4	840.0	68.1	8.11
Medium: [2]							
Husk tight	20	198	9.9	12.9	775.6	53.3	6.87
Husk loosened	8	80	10.0	17.1	880.2	158.2	17.97
Long,[3] husk tight	10	100	10.0	11.7	639.9	9.8	1.53

[1] 0 to 1.5 inches long. [2] 1.5 to 3 inches in length. [3] 3 inches or longer.

[2] PHILLIPS, W. J., and BARBER, G. W. See footnote 1.

BREEDING CORN TYPES TO PROMOTE CANNIBALISM

The husk of the corn ear, if perfectly developed, would afford almost complete protection for the seed. If the corn plant in the course of its development ever occurred without a husk, thus freely exposing the seed to the attack of insects, birds, and mammals, man could hardly have improved the plant better than by introducing the husk to protect the ear. Since in many varieties of corn the husk in its present form does not completely envelop the ear, it can, no doubt, be still further improved through plant breeding. To take advantage of such a peculiar and well-fixed instinct as cannibalism of the ear worm larvae, the improvement of the ear should be such as to limit the points of entry and the feeding space available to the larvae. This can best be accomplished by developing a longer husk, which will completely surround the ear and the silk for from 4 to 6 inches beyond the tip, and which will throughout its length be tightly wrapped about the ear. An improved corn ear of this type, as proposed by Kyle,[3] would not only result in generally decreased populations of this insect through an intensification of cannibalistic feeding, but would make more difficult attack by other insect enemies, such as weevils and grain moths. Moreover, with a reduction in numbers of the ear worm other crops attacked by these larvae would probably be benefited.

SUMMARY

Cannibalism is shown to be a well-fixed habit among corn ear worm larvae. When feeding in corn ears or in small cages, they attack one another with great voracity, not only killing but completely devouring their fellow larvae.

Although this habit seems to be most highly developed in the older larvae, it is characteristic of all larval instars, the intensity of its manifestation at any time depending on the size of the larvae, their number, and the degree of crowding to which they are subjected. In experiments in which various numbers were confined in salve-box cages never did more than one individual in each cage become full grown and pupate.

Individuals were reared to adults from all larval instars and from the egg, when fed entirely upon maimed ear worm larvae, provided the food material was kept fresh. Ear worms reared under such conditions usually required about one-half more time to develop from egg to adult than those maintained on the usual diet of combined plant and animal food. Individuals reared solely on the animal food were of normal size and vigor.

Most larvae developing in corn ears where the insect is numerous apparently subsist on a mixed diet consisting of corn silks and kernels and other ear worm larvae. When offered a choice of such foods in cages, the larger larvae accepted the animal food much more readily than did the smaller larvae.

One ear worm larva in a cage, feeding entirely as a cannibal, consumed about 20 fellow larvae of about its own size in the several instars through which it passed to complete its growth, but by progressive cannibalistic feeding—larvae feeding upon others, which had fed upon others, and so on—it is possible, after several days or weeks, to find one larva remaining in an ear of corn, the sole representative of a larger population that entered the ear to feed.

[3] KYLE, C. H. SHUCK PROTECTION FOR EAR CORN. U. S. Dept. Agr. Bull. 708, 16 pp., illus. 1918.

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The extent to which cannibalism by ear worm larvae occurs in ear corn depends largely on the character of the husk, whether it is loose or tight, and on its length relative to the ear, as this determines the points of entry of larvae into the ear and the feeding area within the ear. The most rapid and extensive reduction in numbers through cannibalism occurs in ears having long, tightly wrapped husks, because they present the fewest points of entry and larvae that do enter are brought into closest contact with one another. There is consequently much greater grain injury in ears that are poorly protected by the husks and thus permit larger numbers of larvae to survive cannibalism.

Cannibalism in the corn ear worm can be increased with benefit by improving the nature of the husk protection to corn ears. Experiments have indicated that such improved protection would not only result in less injury to corn but also would limit the numbers of ear worms that develop in cornfields, thereby decreasing the likelihood of serious injury to secondary host plants.

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THE FLOUR BEETLES OF THE GENUS TRIBOLIUM

By

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Division of Cereal and Forage Insect Investigations
Bureau of Entomology and Plant Quarantine

UNITED STATES DEPARTMENT OF AGRICULTURE, WASHINGTON, D. C.

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By Newell E. Good

Assistant entomologist, Division of Cereal and Forage Insect Investigations, Bureau of Entomology and Plant Quarantine[1]

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INTRODUCTION

Flour and other prepared products frequently become infested with small, reddish-brown beetles known as flour beetles. These beetles, although very similar in size and appearance, belong to the different though related genera *Tribolium*, *Gnathocerus*, *Palorus*, and *Latheticus*, of the family Tenebrionidae. Of these, by far the most abundant and destructive are the confused flour beetle, *Tribolium confusum* J. du V., and the rust-red flour beetle, *T. castaneum* (Herbst).

These insects are very hardy and able to subsist on any of a wide variety of foodstuffs, and through a world-wide commerce have been

[1] The writer acknowledges his indebtedness to the following persons for their cooperation in the investigations herein reported: To E. A. Back for originally planning and outlining the problem and for the general oversight of the work throughout its progress; to R. T. Cotton for many helpful suggestions; to R. A. St. George for the preparation of the descriptions of the larvae; to K. G. Blair, of England, for a specimen of *T. indicum* and information regarding this species and the synonymy of *T. castaneum;* to J. C. M. Gardner, of India, for specimens of *T. indicum* now in the U. S. National Museum; to the late A. M. Lea, of Australia, for information regarding *T. myrmecophilum;* to J. A. Hyslop for many of the distribution records and some of the records on foods; to Paul Bartsch, E. A. Chapin, and H. S. Barber for much helpful criticism regarding the taxonomic portion of the bulletin; and to H. B. Bradford for the line drawings.

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transported to regions which otherwise they might never have reached. Thus there are today not only records of their occurrence but numerous references to their destructiveness from practically every civilized country in the world.

SYNONYMIES AND TECHNICAL DESCRIPTIONS OF THE ECONOMICALLY IMPORTANT SPECIES OF TRIBOLIUM [2]

THE GENUS TRIBOLIUM MACLEAY

SYNONYMY OF THE GENUS

1825. *Tribolium* MacLeay (*67*)[3]
Genotype, *Colydium castaneum* Herbst (1797), type by subsequent designation, Lucas, 1855.
1833. *Margus* Dejean (*37*)
Genotype, *castaneus* Sch. (=*castancum* Herbst), type by subsequent designation, Good, 1936.

MacLeay's description of *Tribolium* is sufficiently clear to leave little doubt that he was dealing with a specimen of the species treated as *Tribolium castaneum* in this bulletin. One disturbing factor is the designation of all tarsi as five-jointed. This cannot in itself be taken as constituting grounds for the rejection of the name *Tribolium*, since many mistakes were made by the early Coleopterists in regard to the number of tarsal joints. Concerning MacLeay's description of *Tribolium* Wollaston (*104, p. 491*) says:

> MacLeay, who was the first to characterize the group (in 1825), described it as pentamerous and placed it amongst the *Necrophaga*, which was clearly however an error—perhaps partially to be accounted for by the fact of his having but a single specimen to judge from.

Wollaston goes on to say that he had examined MacLeay's type specimen which was still preserved in the East India Co.'s Museum in London, and, "* * * the careless manner in which it is mounted conceals the hind tarsi altogether from view * * *."

It seems clear that MacLeay proposed his genus *Tribolium* for the true *Colydium castaneum* of Herbst (1797) and not for any other species the name of which he might have incorrectly synonymized with it. At the head of his description of the genus he says, "Genus TRIBOLIUM, Nobis. *Colydium* Herbst." He calls his species *castaneum*, and puts *Colydium castaneum* Herbst at the head of his synonymical list. Of the other synonyms, only one, *Trogosita ferruginea* Fab., is included without a question mark. But, since *Colydium castaneum* Herbst (1797) antedates *Trogosita ferruginea* Fab. (1801), and since *T. ferruginea* Fab. had never been associated with the genus *Colydium*, and since he calls his species by the same name

[2] The manuscript for this bulletin as originally submitted to the Bureau of Entomology in March 1934 contained a complete revision of the genus *Tribolium*, consisting of the synonymies and descriptions of the 5 species previously known to the author, together with the description of 1 apparently new species. While the manuscript was being reviewed, a paper by Uyttenboogaart (*98*) appeared that covered much of the systematic work of this manuscript. *Tribolium destructor* Uyttenb. was found to be the same species as the apparently new one described in the original manuscript of this bulletin, so Uyttenboogaart's name was substituted as that of the describer. In the bulletin as now issued the systematic portion has been limited to the economically important species, so the species *T. indicum* Blair, *T. myrmecophilum* Lea, as well as Uyttenboogaart's *T. gebieni* are not treated here.

[3] Italic numbers in parentheses refer to Literature Cited, p. 51,

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as that of Herbst, there is no question but that MacLeay would have designated *Colydium castaneum* Herbst as the type of his genus *Tribolium*, if it had been customary at that time to designate a genotype, which unfortunately was not the case. Furthermore, the first definite designation of a type for the genus *Tribolium* is that of Lucas (*66, p. 259*), who stated in 1855 "L'espèce type représentant ce genre, est le *Tribolium* (*Colydium*) *castaneum*, Herbst, Nature. Insect., tom. 7, p. 282, N°. 3, pl. 112, fig. 13 E (1797)."

The name *Margus* was first used by Dejean in 1833 (*37*) in the following manner:

Margus Dejean.
{Ferrugineus Fab. (Trogosita) India orient.
{castaneus Sch. (Tenebrio) Gallia.

He considered *castaneus* Sch. as a synonym of *ferrugineus* Fab. This entry was repeated in his 1837 catalog. In 1842 William Redtenbacher (*83*) used the name *Margus* as the generic name for what he considered a new species, *Margus obscurus*, but which later was found to be a synonym of *Tribolium madens* Charp. In 1845 L. Redtenbacher (*81*) separated *Margus* from *Tenebrio* in a descriptive key without mention of any species, and in 1849 (*82*) he gave a description of the genus *Margus* and of the species *ferrugineus* Fab. and *madens* Charp., which he listed under this genus. There can be no doubt that *Margus* of Redtenbacher is the *Tribolium* of this bulletin. The name *Margus* has since been used in a number of instances, especially in France, in treating of *Tribolium*. However, the writer has been unable to find a designation of a genotype for *Margus* in any of the literature dealing with this genus. There is, therefore, the choice between *ferrugineus* Fabricius and *castaneus* Schönherr, which Dejean thought to be synonymous. Since *Tenebrio castaneus* Schönherr (1806), as conceived by Schönherr, is a complex, embracing several species, the writer now restricts this name (since this has not been done before) to the fraction which Herbst called *Colydium castaneum* in 1797. Likewise, since *Margus* of Dejean (1833) embraces two species (*ferrugineus* Fab. and *castaneus* Sch.) the writer hereby selects *castaneus* Schönherr (=*castaneum* Herbst) as the genotype of *Margus* Dejean.

Regarding the *Stene* of Stephens (*95*) the writer is convinced from a study of Stephens' description that the specimens he had before him, and from which he made his description, were the *Tribolium castaneum* Herbst of this bulletin. However, since Stephens erected his genus for the *Tenebrio ferrugineus* of Fabricius, there is no alternative but to consider *Stene ferruginea* Stephens as a synonym of *Tenebrio ferrugineus* Fab. Since *Stene* is the first nonpreoccupied generic name for this species, *Stene ferruginea* (Fab.) becomes the valid name of the species originally described as *Tenebrio ferrugineus* by Fabricius in 1781. This species is now known to the writer only by the type specimen, which is considered a cucujid by prominent English coleopterists.

DESCRIPTION OF THE GENUS

Sexes externally alike. Color usually ferruginous, chestnut brown to black, sometimes with portions reddish. Body rather flattened or depressed. Clypeus much enlarged and with genae forming a shelflike projection extending around

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sides and front of head from eye to eye. Eyes rather large, emarginate or nearly divided by genae. Antennae 11-jointed, always enlarged toward tip, or clubbed; club 3- or 5-jointed or gradual, but never 2-jointed. Labrum short, transverse; mandibles short, equal in the two sexes. Prothorax nearly square or slightly wider than long, weakly bisinuate at base, rounded on sides, punctate or rugulose. Legs sparsely hairy, front tibia slightly enlarged toward tip; tarsi slender, middle coxa without trochantin. Elytra punctate-striate, sometimes rugulose, the intervals more or less raised in sharp carinae; epipleurae very narrow at tip. Wings present, usually functional. Ventral surface of abdomen weakly punctate. Length 3 to 6 mm.

KEY TO THE SPECIES OF TRIBOLIUM

1. Some or all of elytral intervals more or less raised or carinate; terminal joint of antennae either square, rounded, or largest at base; body not broad and rounded ---------- Subgenus *Tribolium* ---- 2.
   All intervals of elytra smooth and flat; terminal joint of antennae small and in the shape of an inverted triangle; body broad and rounded ---- Subgenus *Leanum* ---- 7.
2 (1). Body uniformly ferruginous ---- 3.
   Body black, maroon, or dark castaneous ---- 5.
3 (2). Length 3.0 to 3.9 mm; punctation moderate, prothorax smooth and shiny; intervals of elytra moderate ---- 4.
   Length 5.0 to 5.5 mm; punctation coarse and close; prothorax roughened and dull; elytral intervals raised into rather sharp carinae ---- *gebieni.*
4 (3). Antennae with a distinct three-jointed club; space separting eyes ventrally equal to diameter of eye; eyes not margined above; genae fairly prominent ---- *castaneum.*
   Antennae gradually enlarged; space separating eyes ventrally equal to three times the diameter of eye; eyes margined above; genae very prominent ---- *confusum.*
5 (2). Body dark maroon or dark casteneous; antennae gradually enlarged or with an indistinct five-jointed club; space separating eyes ventrally not more than twice the diameter of eye; eyes margined above ---- 6.
   Body black, appendages reddish; antennae with a distinct three-jointed club; space separating eyes ventrally equal to about three times the diameter of eye; eyes not margined above ---- *madens.*
6 (5). Length 4.5 to 5.5 mm; color dark maroon with appendages lighter; first and second intervals of each elytron smooth; prothorax not rugulose; space separating eyes ventrally equal to nearly two times the diameter of eye ---- *destructor.*
   Length 3.2 to 4.2 mm; color uniformly dark castaneous; all elytral intervals raised into sharp carinae and very prominent; prothorax rugulose; space separating eyes ventrally slightly less than the diameter of eye ---- *indicum.*
7 (1). Tibiae stout; hind tarsi robust, first joint short, somewhat triangular; apex of prothorax narrower than base; scutellum very small, semicircular; space separating eyes ventrally equal to one and two-thirds times the diameter of eye; length 4.3 to 4.6 mm ---- *myrmecophilum.*

SYNONYMIES AND DESCRIPTIONS

TRIBOLIUM CASTANEUM (HERBST)

SYNONYMY

1797. *Colydium castaneum* Herbst (*50, pt. 7*).
1806. *Tenebrio castaneus* Schönherr (*90, p. 153*).
1810. *Phaleria castanea* Gyllenhal (*49*).
1821. *Uloma ferruginea* Dejean (*36*).
1825. *Tribolium castaneum* MacLeay (*67*).
1833. *Margus castaneus* Dejean (*37*).
1839. *Stene ferruginea* Westwood (*102*).
1854. *Tribolium ferrugineum* Wollaston (*104*).

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A list of the names usually cited as synonyms of *T. castaneum* (Herbst) but which do not refer to this species is given in table 1.

TABLE 1.—*List of names wrongly synonymized with Tribolium castaneum (Herbst)*

Date	Name and author	Habitat	Collection of	Remarks
1775	*Dermestes navalis* Fab.	New Zealand	Banks	Probably a dermestid. See *D. navalis* Fab. 1781 and 1787, and *Lyctus navalis* Fab. 1775 and 1787.
1781	do	do	do	Text same as *D. navalis* Fab. 1775 and 1787.
1781	*Tenebrio ferrugineus* Fab	Equatorial Africa	do	Cucujidae, teste Waterh. 1896, Champ. 1896, Blair 1913.
1787	*Dermestes navalis* Fab.			Text same as *D. navalis* Fab. 1775 and 1781. See *Lyctus navalis* Fab. 1792.
1787	*Tenebrio ferrugineus* Fab.	Saxony	Hybner	Homonym of *T. ferrugineus* Fab. 1781. See *T. ferruginea* Fab. 1792.
1792	*Trogosita ferruginea* Fab.	Equatorial Africa	Banks	Synonym of *Tenebrio ferrugineus* Fab. 1787, teste Fab.
1792	*Lyctus navalis* Fab.	New Zealand	do	Antennal club 2-jointed. Synonym of *D. navalis* Fab. 1787, teste Fab.
1792	*Dermestes navalis* Herbst	do	do	Synonym of *D. navalis* Fab. 1775, 1781, 1787, teste Herbst.
1792	*Ips cinnamomea* Herbst	Germany	Hellwig	Illustration cannot refer to a *Tribolium*.
1795	*Tenebrio ferrugineus* Olivier.	Equatorial Africa	Banks	Synonym of *T. ferrugineus* Fab. 1781, 1787, Linn. 1790 and *Trogosita ferruginea* Fab. 1792, teste Olivier.
1798	*Ips testacea* Fab.	Eastern India	Daldorf	See *Trogosita ferruginea* Fab. 1801.
1801	*Trogosita ferruginea* Fab.	India		Synonym of *T. ferruginea* Fab. 1792, *Lyctus navalis* Fab. 1792, *Ips testacea* Fab. 1798, teste Fab.
1806	*Tenebrio ochraceus* Melsh	Pennsylvania		Catalog reference only.
1812	*Tenebrio bifoveolatus* Duft.	Austria	Duftschmid.	Length 2⅔ mm. *Palorus* teste Chapin.
1832	*Stene ferruginea* Stephens	England	Stephens	Genus *Stene* created by Stephens for *Tenebrio ferrugineus* Fab.
1836	*Uloma ochracea* Knoch	North America		Catalog reference only.
1836	*Uloma rubens* Dej.		Dejean	Do.
1840	*Uloma rubens* Cast.	North America	do	Length 6⅔ mm, width 2⅓ mm. Probably *Uloma*.
1847	*Margus ferrugineus* Kuster.	Europe		Length 2⅔ mm, width ⅔ mm. Probably *Palorus*.

The species *Tribolium castaneum* has been generally known in North America and elsewhere as *Tribolium ferrugineum* Fab. (1781 or 1787), but it is very evident that the name *ferrugineum* Fab. cannot be retained. The type of *Tenebrio ferrugineus* Fab. (1781) was examined by Waterhouse (*100*) in 1896 and found to be quite different from the insect known as *Tribolium ferrugineum* Fab. In this type specimen, in addition to other characteristics excluding it from the Tenebrionidae, all of the tarsi were four-jointed, and Waterhouse placed it among the Cucujidae. Champion (*16*) and Blair (*9*) also examined this type specimen and corroborated the opinion of Waterhouse that it was a cucujid. Champion, Waterhouse, and Blair, all seem satisfied that the specimen in question is the identical one described by Fabricius in 1781, and, although the identity of any specimen is, at best, very uncertain after 115 years, the concerted opinion of these three eminent coleopterists as to the specimen's identity and its proper classification seems of sufficient weight to insure its acceptance. Since 1896 the description of *Tenebrio ferrugineus* Fab. (1787) has been generally accepted as the original description of the species. However, this name is an exact homonym of that of the 1781 insect and could not be used even if Fabricius had been dealing with another species. Whether Fabricius really

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was dealing with another species is not certain although Blair (*9*) thinks not. He says:

> The description of *Trogosita ferruginea*, Ent. Syst. I, 1792, quite disposes of this possibility, for here it is definitely synonymised with the *Tenebrio ferrugineus* of the "Mantissa", and Fabricius continues: "Habitat *in Africa æquinoctiali Mus. Dom. Banks*, in Americæ Insulis Dr. Pflug," the words in italics being obviously quoted from the Species Insectorum, 1781. It is perfectly clear, therefore, that Fabricius supposed that he was dealing with one and the same species in these three instances. Furthermore, this conclusion is borne out by Sherborn's "Index Animalium" which quotes *Trogosita ferruginea* (1792) as synonymous with *Tenebrio ferrugineus* (1781), and in the "Epitome Entomologiae Fabricianae", by Bergsträsser, p. 18, where *Trogosita ferruginea* is the only one that appears. From these facts, then, it is evident that the name *ferrugineum*, F. as applied to the *Tribolium*, can have no *locus standi* whatever.

Dermestes navalis Fab. (1775) has been thought by some authors to refer to the present species. The listing of *Lyctus navalis* as a synonym of *Trogosita ferruginea* by Fabricius in 1801 may be the basis for the use of the name *navalis* by Reitter in 1911. That this cannot be correct is evident for several reasons. The description states that it is of the form of *Dermestes murinus* but one-fourth smaller, which very evidently does not refer to a *Tribolium*. In 1792 Fabricius described a *Lyctus navalis* with a 2-jointed club on the antenna and synonymized it with his third description of *Dermestes navalis* (1787). His three descriptions of *Dermestes navalis* (1775, 1781, and 1787) are almost identical in wording, name, habitat, and collection, except that no habitat or collection is given for the 1787 description. From this it seems perfectly evident that Fabricius was dealing with the same species and perhaps the same specimen in all four of his descriptions of *navalis*, and that it cannot be the present species is certain because he described it as having a 2-jointed club on the antenna instead of a 3-jointed one.

Ips cinnamomea Herbst (1792) is sometimes given as a synonym but certainly cannot refer to this species because Herbst (*50, pt. 4*) begins by saying that it has exactly the form but not the size of the first (*Ips quadripunctata*), which certainly differs very greatly from a *Tribolium*, and because from the figure given one needs to stretch his imagination considerably to place it anywhere near *Tribolium*.

The description of *Colydium castaneum* Herbst (1797) fits the present species very well with one exception. His description of the tarsi (*50, pt. 7*) states "die Füsse sind wie gewöhnlich", which is four joints for all of the tarsi in the genus *Colydium*. However, as has been stated, the designation of any certain number of tarsal joints to a beetle, especially a tenebrionid, by these early coleopterists should not be taken too seriously. In this respect it is significant to note that MacLeay, in proposing his genus *Tribolium* for the *Colydium castaneum* of Herbst, which was originally described as having all the tarsi 4-jointed, nevertheless designated all the tarsi as 5-jointed. Apparently, because of imperfect lenses, neither of these authors was able to determine the exact number, and neither suspected that his insect might be heteromerous. Furthermore, Herbst states that his insect was taken as a museum pest, damaging insects in a collection. After eliminating the dermestids, to which the description cannot possibly refer, there are left, in addition to this *Tribolium*, so few insects known to be museum pests that it is an easy matter to see that

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none but *T. castaneum* fits the description. Finally, Herbst's illustration of his *Colydium castaneum* (fig. 1) is sufficiently clear to be recognizable as referring to *T. castaneum*, even without the description or food record; and when considered in connection with the description and especially with the remark as to its food in this particular instance, all question as to its identity is removed.

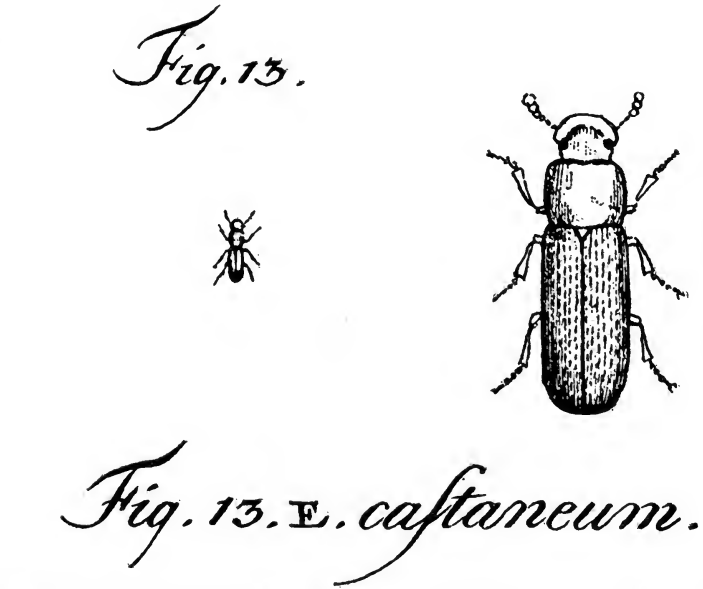

FIGURE 1.—Reproduction of Herbst's original illustration of *Colydium castaneum* (*50, pt. 7*), 1.82 times the size of the original illustration.

DESCRIPTION

(Fig. 2.)

Color uniformly ferruginous or reddish brown.

Head: Clypeus fused with front. Genae in front of eyes moderately widened and forming an angle of about 60° with the eye, this shelflike projection extending forward from eyes and continuing around the clypeus but truncate and not particularly expanded at front of head. Surface of head irregular; a shallow, transverse depression running across head in front of eyes and another just back of eyes; upper surface rather densely punctate, under surface finely and sparsely punctate. Eyes emarginate, the emargination extending backward for about one-third length of eye. Epicranium not margined above eye, front and eye forming a nearly continuous line. Viewed from below, eyes transversely ovate and very large, the width of each eye being equal to or only slightly less than the distance separating them. Antennae with the three terminal joints suddenly enlarged, forming a distinct club, the ninth joint being nearly twice as wide as the eighth; terminal joint transversely rounded, or transversely ovate. Labrum very short, transverse, hairy. Mandibles short, bifid at the tip. Maxillary palpi with last joint oval, obtuse at apex. Labial palpi with last joint subovate.

Prothorax widest at middle, front margin little or no wider than rear margin; sides rounded. Front angles gradually rounded, front margin nearly truncate; rear angles slightly obtuse; rear margin strongly bisinuate. Moderately punctate above, less so below. Scutellum nearly semicircular or semihexagonal with rounded angles. Elytral intervals fairly prominent but usually less so than the lines of punctures, which are of a darker color than other parts of the elytra; these characters rather variable. Margins of epipleurae extending

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slightly below lateral margins of body except caudad of third abdominal segment. Wings fully developed, functional. Legs rather slender, front tibiae slightly widened apically, fore and middle tibiae moderately serrate on outer margins; all tibiae with two short terminal spines; all tibiae and tarsi sparsely ciliated.

Abdomen finely punctate over entire surface. Lateral margins of first and second segments smooth, parallel; third slightly converging, with a very small rounded projection on each side at apex; fourth short, also more contracted laterally, with a small, rounded projection on each side at two-thirds the distance from base to apex; fifth semicircular, the projections slightly larger than on fourth segment and situated near base, with a slight indentation immediately to the rear of these projections. Sutures between all segments parallel, except at lateral margins. Fourth segment hardly more than one-half the length of the second; third three-fourths the length of the second.

Length 3.00 to 3.73 mm, average 3.323 mm; width 0.97 to 1.26 mm, average 1.143 mm.

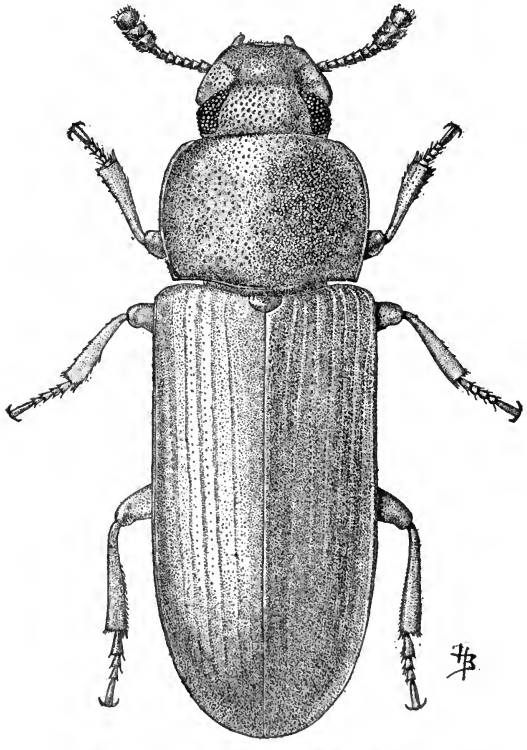

FIGURE 2.—*Tribolium castaneum:* Adult, × 28.

Habitat.—Cosmopolitan, in cereal products, etc.
Type locality.—East Indies.

TRIBOLIUM CONFUSUM JACQUELIN DU VAL

SYNONYMY

1854. *Tribolium ferrugineum* Mulsant, (*70*).
1868. *Tribolium confusum* Jacq. du Val, (*55*).
1891. *Tribolium* (*Stenc*) *confusum* Seidlitz, (*91*).

Mulsant in 1854 misidentified the present species, calling it *Tribolium ferrugineum* Fab. The fact that the name *T. ferrugineum*

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was applied to this has therefore no status as far as its antedating the present name is concerned.

The name *Stene* was incorrectly used by Seidlitz in 1891 (*91*) and 1894 (*92*) as a subgeneric name for *T. confusum* J. du V., which he separated from *T. castaneum* Herbst and *T. madens* Charp. on the basis of antennal characters. He disregarded the fact that Stephens' *Stene* actually referred to *T. castaneum* and so could not be used as he suggested even if, as was shown in the discussion of the synonymy of the genus, this name was not entirely thrown out of the group for nomenclatorial reasons.

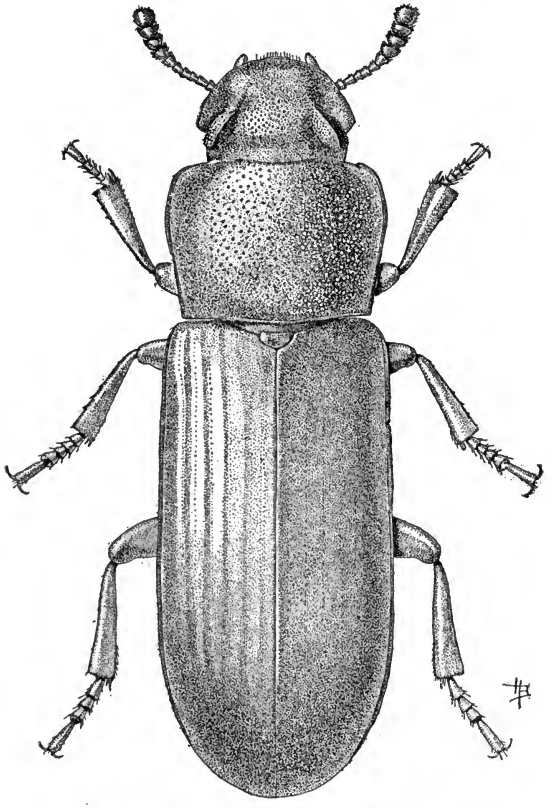

FIGURE 3.—*Tribolium confusum:* Adult, × 28.

DESCRIPTION

(Fig. 3.)

Color fairly uniform, reddish brown or ferruginous.

Head: Genae in front of eyes distinctly widened, jutting out at nearly a right angle with them and, with the clypeus, forming a thin, shelflike projection around front of head, the expanded clypeus rounded anteriorly. Eyes decidedly emarginate, the emargination extending backward to middle of eye. Epicranium sharply margined immediately above the eye, forming a horizontal carina slightly jutting out over the eye. These characters make the eyes appear much smaller than in *castaneum*. Viewed from below, the eyes are rounded, the space between the eyes being nearly three times the observed width of the eye. Antennae gradually enlarged toward tip, the expansion

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taking place mainly in the seventh to tenth joints, but the ninth only slightly larger than the eighth. Terminal joint round or transversely rounded. Antennae sparsely hairy. Mouth parts similar to those of *castaneum*.

Prothorax widest at apical third, distinctly wider at front margin than at rear margin; front angles sharply rounded, projecting slightly anterior to the straight line forming the remainder of the front margin; hind angles usually right angles, rear margin weakly bisinuate. Scutellum semihexagonal. Elytral intervals fairly prominent, usually more noticeable than the lines of punctures. Margins of the epipleurae nearly coinciding with those of the sternites. Wings fully developed. Legs similar to those of *castaneum*.

Abdomen similar to that of *castaneum* but with the projections on the third, fourth, and fifth segments slightly more pronounced.

Length 3.09 to 3.82 mm; average 3.457 mm; width 1.08 to 1.26 mm; average 1.179 mm.

Habitat.—Cosmopolitan, in cereal products, etc.

Type locality.—France.

TRIBOLIUM MADENS (CHARPENTIER)

SYNONYMY

1825. *Tenebrio madens* Charpentier, (*25*).
1832. *Uloma madens* Krynicki, (*61*).
1842. *Margus obscurus* Redtenbacher, (*83*).

DESCRIPTION

(Fig. 4.)

Color of body dull black; legs, antennae, and mouth parts reddish.

Head closely but finely punctate uniformly over the dorsal surface, the pits shallow and usually elongate. Ventral surface moderately punctate with fine pits. Clypeus concave along center of front margin, the sides directly above the base of antennae also slightly concave and raised. Clypeus separated from genae by an indistinct suture but not separated from frons. Frons smoothly rounded or slightly arched. Genae scarcely projecting from curvature of the eyes. Eyes divided by genae for only about one-fourth of their length. Epicranium not at all margined above eyes. Eyes ventrally small and rounded. Space separating them usually 2½ to 3½ times the diameter of eye. Antennae with a very distinct three-jointed club as in *T. castaneum*. Antennal joints narrow up to eighth, which is slightly wider than long, ninth, tenth, and eleventh flattened and much wider than long. Terminal joint large, as broad as tenth and truncate on end. Labrum transverse but rounded on front. Last joint of maxillary palpi slender. Width of head across eyes 0.63 to 0.74 mm; width across genae scarcely any greater.

Prothorax one and one-third times as broad as long, somewhat flattened. Fairly evenly punctate over entire dorsal surface, but somewhat more densely so toward sides; pits hexagonal. More deeply and coarsely punctate than that of *T. castaneum*. Front margin very slightly and evenly bowed forward. Margins of front angles slightly but definitely jutting forward. Sides of prothorax rather sharply margined. Side margins convex to one-third from front angles thence converging regularly to hind angles which are slightly obtuse. Rear margin feebly bisinuate. Base of prothorax impressed on each side of center. Ventral surface of prothorax closely and deeply punctate. Scutellum broadly semihexagonal. Elytra somewhat broader in proportion to length than in *T. castaneum*. Broadest at one-third from apex. First and second intervals smooth, third and fourth slightly raised, fifth, sixth, and seventh slightly carinate, eighth less so, ninth and tenth nearly smooth. Finely and closely punctate, usually with two rows of pits between each interval, those on the disk indistinct. Epipleura narrowing gradually from base to apex. Margins of epipleura nearly coinciding with those of sternites. Wings well developed, functional. Legs similar to those of *T. castaneum* but with serrations of front and middle tibiae absent or nearly so. Tibial spines straight.

Abdomen evenly and finely punctate over entire ventral surface. Lateral rounded projections more reduced than those of *T. castaneum*. Fifth segment with a shallow impression on each side of center. Average length of abdominal

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segments: first, 0.44 mm; second, 0.35 mm; third, 0.32 mm; fourth, 0.24 mm; fifth, 0.32 mm; total length of abdomen, 1.67 mm.

Length, 3.6 to 4.4 mm; width across elytra, 1.2 to 1.6 mm.

Habitat.—Europe, North America, Egypt. Under bark and in rotting logs, occasionally in flour and seeds.

Type locality.—Silesia.

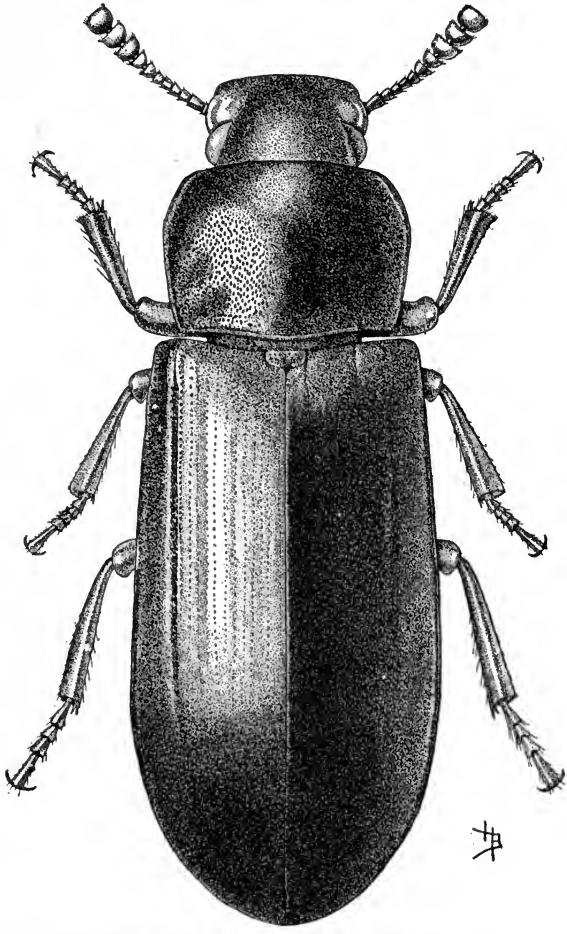

FIGURE 4.—*Tribolium madens:* Adult, × 28.

TRIBOLIUM DESTRUCTOR UYTTENBOOGAART

SYNONYMY

1933. *Tribolium destructor* Uyttenb. (*71, pp. xli–xlii*)

DESCRIPTION

(Fig. 5.)

Color of body dark maroon shining; appendages lighter and more reddish.

Head fairly strongly punctate, the pits elongate and often running together, especially on frons, to form minute, crooked grooves. Ventral surface of head

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sparsely and finely punctate. Clypeus truncate in front, sides rounded, separated from genae by a suture, but not separated from frons. A shallow transverse impression running across the head from front of one eye to the other, and another, incomplete, shallow transverse impression between frons and apex. Eyes divided by the genae for about three-fifths of their length; narrowly margined above. Ventrally moderate in size, the space separating them being equal to from 1½ to 2 times the diameter of each eye. Antennae gradually enlarged or with a very indistinct 4- or 5-jointed club which is sparsely hairy. First joint of antennae concealed by clypeus, joints 1 to 5 narrow, the sixth beadlike, the seventh and eighth progressively broader, the ninth and tenth twice as broad as long, terminal joint broadly rounded to oblong. Labrum short and very transverse; hairy. Mandibles large, bifid, and pointed at tip. Maxillary palpi large, broadly oval. Width of head across genæ 0.82 to 0.99 mm; width across eyes 0.80 to 0.93 mm.

Prothorax 1.00 to 1.25 mm long, 1.25 to 1.55 mm broad; closely and coarsely punctate or pitted, but with the portions between pits smooth and shining. Pits hexagonal or diamond shaped. Upper surface of prothorax moderately arched, sides rounded, broadest one-third from apex; sides of prothorax margined, more strongly so at the front angles, which project forward rather prominently; rear angles obtuse, rear margin bisinuate. Two prominent longitudinal depressions extend slightly forward from the base, one on each side of the midpoint, half way between it and the rear angles. Ventral surface of prothorax closely and coarsely punctate. Ventral surface of mesothorax and metathorax moderately punctate. Scutellum broadly semihexagonal. Elytra more rounded than those of *T. castaneum*. The first two intervals between the rows of pits nearly flat and without carinae, the third elevated at base but less so toward the apex, the fourth, fifth, and especially the sixth and seventh intervals distinctly carinate, the eighth less so, and the ninth nearly flat. Disk of elytra with indistinct rows of pits together with a general punctation and smaller pits. Rows of pits between fourth and seventh intervals distinct and consisting of a central distinct row of pits together with an accompanying row of pits on either side directly at base of each carina. Epipleurae moderately broad back to base of the last abdominal segment, thence very narrow. Margins of epipleurae nearly coinciding with sides of abdominal segments. Wings well developed. Legs similar to those of *T. castaneum*, but with serrations of front and middle tibiae absent or nearly so and with the ventral groove of the prothoracic femora more pronounced. All tibiae terminated by two straight spines, the anterior spine of prothoracic tibiae much larger than the others.

Abdomen moderately pitted over entire ventral surface. Length of first segment with intercoxal process 0.46 to 0.58 mm, second segment 0.40 to 0.43 mm, of third segment 0.36 to 0.39 mm, of fourth segment 0.26 to 0.29 mm, of fifth segment 0.38 to 0.43 mm, total length of abdomen 1.8 to 2.1 mm. Margins of abdominal segments differing from those of *T. castaneum* in that the lateral rounded projections are absent or very much reduced on the third and fourth segments and reduced on the fifth.

Length 4.3 to 5.4 mm, width across elytra 1.4 to 1.8 mm.

Habitat.—Recently found to be a pest in seeds and various cereal products in Germany and the Netherlands.

Type locality.—Erfurt, Germany.

HISTORY AND ECONOMIC IMPORTANCE OF THE GENUS TRIBOLIUM

COMMON NAMES

The flour beetles are known by a variety of common names. Millers refer to species of *Tribolium* and other closely related beetles of similar appearance as "flour beetles", "flour weevils", "red weevils", or "bran bugs." Grain inspectors know them as bran bugs.

The approved common name for *T. confusum* is "the confused flour beetle." It has also been referred to by one of the earlier American entomologists as "the pollard weevil", while in Germany this

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species is commonly called "the American rice-flour beetle." The name "confused flour beetle" is the natural outgrowth of its scientific name which was chosen by Jacquelin du Val because the species had until then been confused with the very similar *T. castaneum*. The accepted common name of the latter is, "the rust-red flour beetle", which is appropriate considering the insect's color but does not differentiate it from its many similarly colored relatives. Other common names for this species found in less recent American literature are "wee flour beetle", "red flour beetle", "ferruginous flour beetle", "brown grain beetle", and "the weevil." In Germany it is commonly called "the red-brown rice-flour beetle."

The common names by which *T. madens* has been called are "the black flour weevil", a name given to it by Johnson in 1897 (*58*), "the black flour beetle", by Chittenden in 1911 (*30*) and "the black-brown rice-flour beetle", by Zacher (*108*) in 1927. The first name is inappropriate, however, as none of this group have any relation to true weevils. Of the other two names the writer prefers the black flour beetle, a name which adequately describes the insect and also is in harmony with the names given to other *Tribolium* and closely related beetles, which are all known as flour beetles.

FIGURE 5.—*Tribolium destructor*: Adult, × 12.

No common names have as yet been proposed for the other species of *Tribolium*, but since these species, with the exception of *T. destructor* Uyttenb., are of no economic importance, there is no need for common names by which to designate them.

PLACE OF ORIGIN OF THE GENUS

As with most stored-product insects, the question of the place of origin of *Tribolium* is very difficult to solve because their distribution by commerce has long since made them cosmopolitan. There is only one definite record which throws any light on the subject. Andres (*3*) records the finding of specimens of *Tribolium* in a Pharaonic tomb of about 2500 B. C. At that time commerce, the only means by which these insects are distributed, was largely restricted to the Mediterranean region and southern Asia. Another hint is given by Blair (*10*) in evidence showing that *T. castaneum* is commonly found in the wild state in wood in India. It is also found in such situations in North America and elsewhere, but not at all commonly. In the same article Blair described a closely related species, *T. indicum*, from the same country and with the same habitat which does not occur in stored products. From these facts it seems probable that these beetles originated somewhere in the general region comprising India, southwestern Asia, and the eastern Mediterranean lands.

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The fact that *T. gebieni* was described from Paraguay and so far has not been recorded elsewhere has no meaning whatever so far as its origin is concerned. It was not described until 1933, and there is no indication of its habitat or food habits. It seems quite probable that *T. gebieni* is a native of some other country where it still awaits discovery and that it has been transported to Paraguay by commerce.

Another species, *T. myrmecophilum*, is known only as an inhabitant of ants' nests in southeastern Australia and cannot fit into any present theory as to the origin or original habitat of the genus. It may be that later this species will be discovered in other localities and with other habits, or may be placed in a separate genus, but at present the writer does not propose to offer any explanation for this seeming discrepancy in his theory.

It is almost certain that before the advent of civilized man the members of this group lived under bark and in old logs. In that case

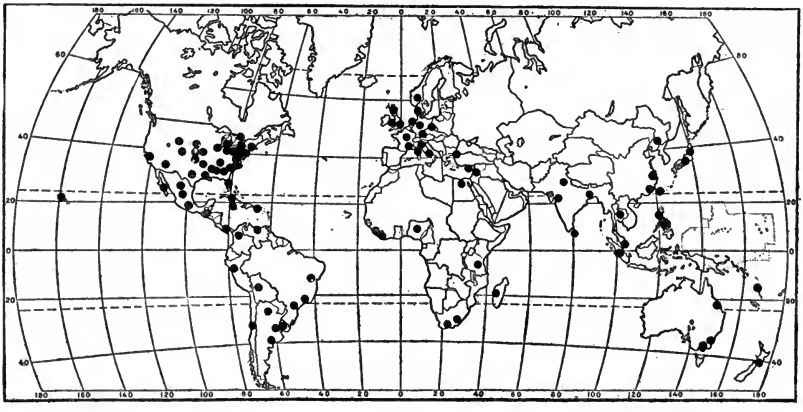

FIGURE 6.—Distribution of *Tribolium castaneum* as shown by records of the Bureau of Entomology and Plant Quarantine, United States Department of Agriculture. In the United States each infested State is represented by a dot, the infestation being shown more in detail in figure 8.

their food habits were probably those of scavengers, but of this there is no certainty. With very few exceptions, the beetles of the subfamily Ulominae, of which *Tribolium* is a member, occur either as pests of stored products or else under the bark of trees and in rotting logs. It seems very probable that the members of this group originally lived in the latter habitat and that the flour-feeding species have since become adapted to their present mode of life. The genus *Tribolium* presents all gradations between the two. *T. indicum* lives under bark only, *T. madens* usually occurs there but has been taken in seeds and in meal on a few occasions; while *T. confusum* and *T. castaneum* are essentially pests of stored products, although sometimes found under bark, and *T. destructor* has so far been recorded only from seeds and other stored products.

DISTRIBUTION

Tribolium confusum and *T. castaneum* are cosmopolitan, occurring all over the world wherever stored cereal products are to be found (figs. 6, 7, 8, and 9). As they live inside of buildings and may easily

be carried from place to place in small quantities of foodstuffs, these beetles are likely to be recorded from practically any part of the world. The failure of the world-distribution maps to show any appreciable difference in the northerly distribution of the two species

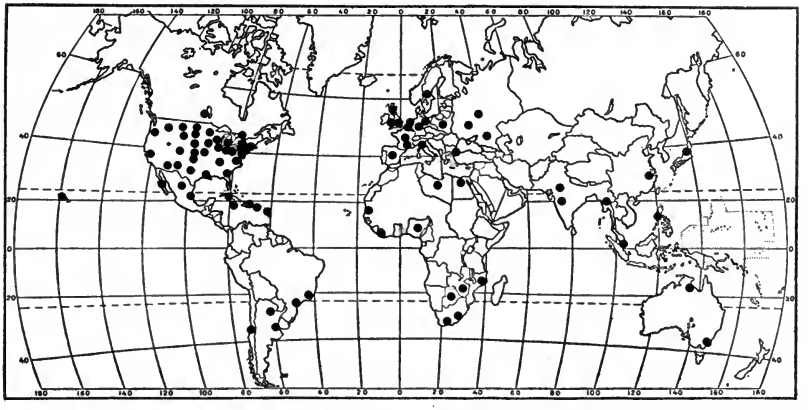

FIGURE 7.—Distribution of *Tribolium confusum* as shown by records of the Bureau of Entomology and Plant Quarantine, United States Department of Agriculture. In the United States each infested State is represented by a dot, the infestation being shown more in detail in figure 9.

is due to the fact that either species may be introduced and become established in heated buildings in climates much colder than they could ordinarily tolerate. Records in the United States indicate that

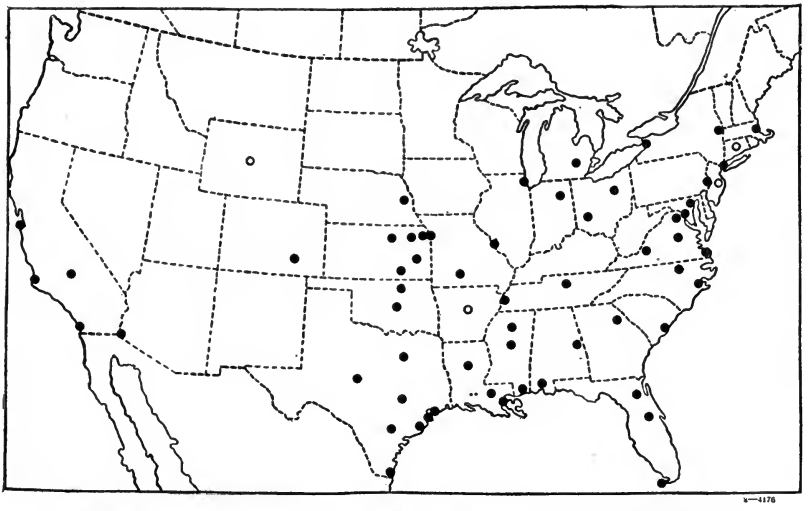

FIGURE 8.—Distribution of *Tribolium castaneum* in the United States.

temperature has quite an effect on distribution. *T. castaneum* is essentially an insect of warm climates, and, although sometimes recorded from Canada and other northern countries, it is evidently not a permanent resident north of the fortieth parallel in eastern

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United States except in heated buildings. *T. confusum*, on the other hand, is more frequently found in the northern part of the United States than in the southern part. From 37° to about 40° N. both species occur commonly, while south of 37° *confusum* gradually

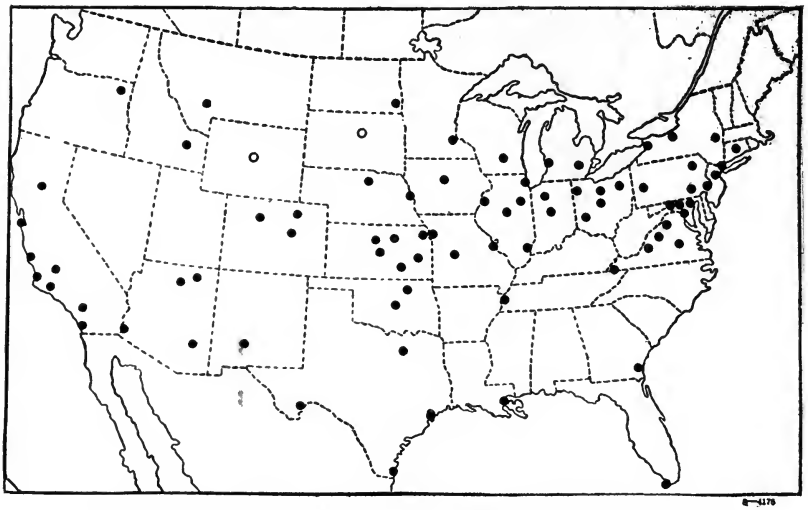

FIGURE 9.—Distribution of *Tribolium confusum* in the United States.

becomes less common and in the Gulf States is largely replaced by *castaneum*.

The localities from which *T. madens* has been recorded are shown in figure 10. It would appear to be of more northerly distribution

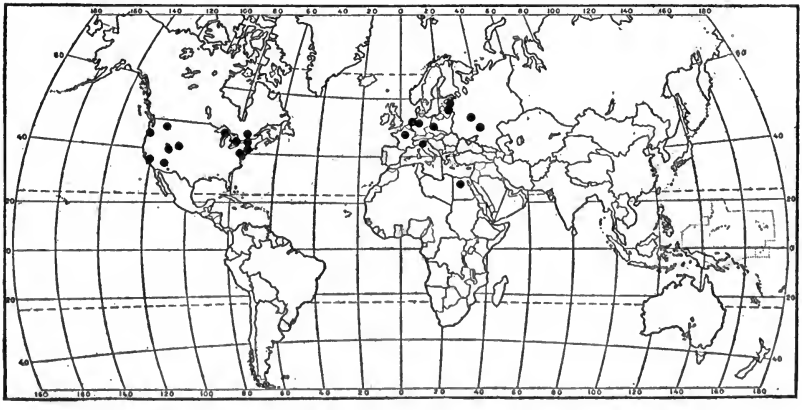

FIGURE 10.—Recorded world distribution of *Tribolium madens*.

and able to withstand greater extremes of cold than any of the other species of *Tribolium*. In this connection it should be remembered that the majority of the records of *T. madens* are from specimens taken out of doors, while all of the records of *T. castaneum* and

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T. confusum from northerly localities are from specimens taken indoors in heated buildings.

T. destructor is found in Germany and the Netherlands; *T. indicum* has been recorded from India, Senegal, and possibly from Abyssinia; *T. myrmecophilum* is known only from southeastern Australia; and *T. gebieni* Uyttenb. is recorded from Paraguay (fig. 11).

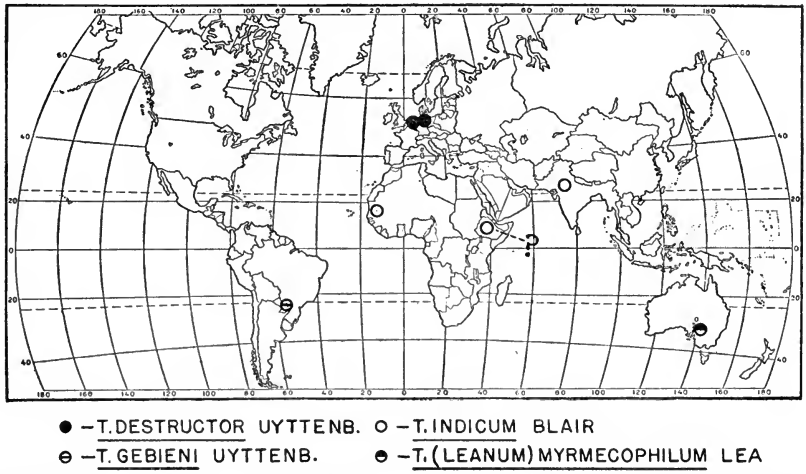

FIGURE 11.—Recorded distribution of other species of *Tribolium;* the species *destructor, indicum, gebieni,* and *myrmecophilum* being indicated by symbols.

HISTORICAL NOTES

DISCUSSIONS OF TRIBOLIUM CASTANEUM AND T. CONFUSUM

Perhaps the most interesting record concerning *Tribolium* is one that goes back over 4,400 years. Andres (*3*) gives the following account:

> Mr. An. Alfieri has supplied me with the following interesting facts in connection with *Tribolium* beetles found in an ancient burial monument. The beetles were found in a jar which probably contained grains or flour in a pharaonic tomb of the 6th Dynasty (about 2,500 years A. C.). Although these insects were still fairly decently preserved it is impossible to establish whether they belong to *ferrugineum* or *confusum* owing that legs and antennae are missing. In any case it is interesting to note that the genus *Tribolium* existed in the Nile Valley since that time and cannot be considered of a recent introduction into the country through importation.

There seem to be no other records antedating the description of *T. castaneum* by Herbst in 1797. It was first recorded in North America in 1835 by Thomas Say (*88*) under the name *Uloma ferruginea* Fab. A good description was given by Wollaston (*104*) in 1854, Lucas (*66*) in 1855, gave a good account of its metamorphosis, while Schiødte (*89*) gave a fine description of the larva in 1878. In 1854 Mulsant (*70*) gave a good description of *T. confusum* under the name of *T. ferrugineum.*

The first to notice a variation in structure of his specimens was Wollaston (*105, p. 496, footnote*) who evidently had specimens of

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both *castaneum* and *confusum* before him, but thought *confusum* to be the male of *castaneum* instead of a new species. His account follows:

> In every diagnosis to which I have had access (including my own, in the "Ins. Mad.") the sexes of *Tribolium* are regarded as perfectly similar (externally) *inter se*. But an accurate inspection has lately convinced me that such is not, in reality, the case,—one of them (which I presume to be the male) being not only less opake and with its prothorax appreciably narrower behind, but having likewise its genæ just perceptibly more prominent and angular in front of either eye, and its antennal club much less abrupt, or more *gradually* formed (occasioned by the subclaval joint, or joints, being wider).

Four years later Jacquelin du Val (*55*) correctly interpreted this variation as constituting a new species and described it as *T. confusum*, the name being chosen because this species had until then been confused with *castaneum*.

One of the first important contributions to the biology of *Tribolium*, and the first from the North American continent, is that of Dugés (*39*) (1883), from Mexico. The first from the United States is that of Lintner (*65*) in 1885, in which he gave an account of the synonymy of *T. castaneum* and its distribution and damage, particularly in New York. Another important contribution to the biology of *T. castaneum* was by Kessler (*59*) in Germany. Some of the earlier American records on *T. castaneum* are those of Cook (*31*) and of Weed (*101*) in 1891, and Bruner (*13*) in 1893, all of which were general accounts concerning this species in various parts of the United States.

T. confusum was not recorded in North America as a distinct species until 1886 when Champion (*15*) recorded it from Mexico. It was recognized in the United States as distinct from *T. castaneum* in the fall of 1893. In 1895 the records of damage by *T. confusum* were numerous.

From 1895 to 1897 Chittenden (*26*, *27*, *28*, *29*) gave the first really important contributions on the genus including data on the biology, distribution, and injury done by all three of the American species. Johnson published many records of injury by these insects beginning with a paper (*56*) in 1895. Quaintance in 1896 (*79*) and 1899 (*80*) published accounts of the biology of both species in Florida. The majority of the numerous short accounts of *Tribolium* between this time and that of Chapman's article in 1918 (*17*) are copied from Chittenden's papers. Good discussions on synonymy were given in 1896 by Champion (*16*) and Waterhouse (*100*) and by Blair (*9*) in 1913, while very acceptable descriptions of the three known species, with keys for identification, were given by Desbrochers des Loges (*38*, *pp. 27–30*) in 1902. *T. castaneum* was recorded in Hawaii by Kotinsky (*60*) as living in bee cells, as feeding on lac in India by Imms and Chatterjee (*54*) and by Roubaud (*87*) as doing considerable damage to peanuts in Senegal. Herrick (*51*) cited several instances of damage by these insects together with a short discussion of their biology. Barnes and Grove (*8*) in 1916 gave notes on the biology of several stored-grain insects in India including *T. castaneum*, and also presented work on chemical experiments, respiration, effect of humidity, and remedial measures.

Chapman (*17*) in 1918 made one of the most important contributions to date concerning the biology of *T. confusum*, including a good

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original account of the life history, food, relative infestation of wheat flour and wheat-flour substitutes, and methods of control.

Short articles on both species appeared in a bulletin by Back and Cotton (*5*) in 1922, a short account of the life history of *T. confusum* was given by Felt (*43*) in 1921, while the effect of *T. confusum* on flour was discussed by Payne (*76*) in 1925.

The more important recent articles on the biology of *Tribolium* are those by Burkhardt (*14*) and Kunike (*62*), giving good accounts of the biology of *T. confusum* in Germany; by Brindley (*12*), which gives much data on the life history and many measurements on the various stages of these beetles; by Good (*47*), in an article intended as preliminary to this bulletin giving a summary of biological experiments on both *T. confusum* and *T. castaneum;* and one by Park (*75*) in 1934, presenting an enlightening and critical analysis of all of the recent important papers on *T. confusum* as well as considerable valuable original data.

The subject of nutritional requirements has been investigated and discussed by Chapman (*19*) and by Sweetman and Palmer (*97*), while the effect of nutrition on sex is discussed by Holdaway and Smith (*53*).

The subject of ecology, and especially that part relating to growth of populations, has received considerable attention within the past few years. In this field, as in many others, the pioneer has been Chapman, whose articles on environment and increase of populations appeared in 1928 (*20*), 1929 (*21*), 1931 (*22*), 1933 (*23*), and 1934 (*24*). Allee (*2*) in 1931 discussed the growth of populations of *T. confusum*, basing his discussion largely on Chapman's work. A mathematical study of the growth of populations of *T. confusum*, also based on the work of Chapman, is presented by Gause (*46*), while Stanley (*93*, *94*) gives more extended mathematical treatises on this subject. Original investigations as well as analyses of previous work were presented in two papers by Park in 1932 (*73*) and 1933 (*74*) on the factors regulating initial growth of populations of *T. confusum*. The effect of moisture on the growth of populations was very well discussed by Holdaway (*52*) in 1932.

An article by Blair (*10*) gives valuable data on food and distribution as well as the original description of another species, *T. indicum*, and Uyttenboogaart (*98*) has presented a revision of the genus and a description of and data concerning *T. destructor*.

Laboratory studies of the effect of low temperature on *T. confusum* were reported by Payne in 1926 (*77*) and 1927 (*78*), while work on the resistance of *T. castaneum* to heat was given by Yokoyama in 1925 (*106*) and 1927 (*107*).

Much emphasis has been placed on the control of these very injurious beetles, but, as would be expected, very little of the work on control concerns *Tribolium* alone. On that relating mainly to *Tribolium* may be mentioned articles by Chapman (*17*), Lehman (*64*) on the use of paradichlorobenzene and naphthalene, DeCoursey (*35*) on trapping in corrugated paper, and by Richardson and Haas (*84*) on the use of pyridine and nicotine. Under the heading of Control Measures (p. 47) will be found references to the more practical discussions by recent investigators.

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HISTORY OF TRIBOLIUM MADENS CHARP.

The first reference to *Tribolium madens* is the description by Charpentier (*25*) in 1825 of a specimen taken from a beehive in Silesia. Redtenbacher's description of *Margus obscurus* in 1842 (*83*) seems to be of this same species. His specimen was taken in Austria. There are various other records of *T. madens* in Europe, but it has usually been taken in rotting wood or similar situations where it was of no economic importance, although it has been recorded as doing damage to flour and cereal products in Russia. Descriptions of *T. madens* have been published by Seidlitz (*92*) and by Des Loges (*38, p. 29*).

The first American record for *T. madens* seems to be a catalog reference by LeConte (*63*) in 1866. Chittenden (*27*) gave a number of records for this species in the United States, but none of these concern cereal products, and he expressed the opinion that it was not found in such situations. Johnson (*57, no. 7*), however, cited a case where it was abundant and causing considerable trouble in a flour mill in Utah in the summer of 1895 and recorded in 1897 (*58*) receiving it in flour and mill products from the States of Montana and Washington. Two specimens in the collection of the United States National Museum were, according to the label, taken in ground cereal in a flour mill at La Grande, Oreg., in August 1897. Other specimens from Bonner, Mont., were taken in meal and cereals. Essig (*42*) referred to it as "another cosmopolitan species" which "occurs in cereals in the west", and from Egypt Andres (*3*) recorded it as being "cosmopolitan in stores." Specimens collected at Newton, Utah, in October 1933 were sent in by G. F. Knowlton with the report that they were very abundant in stored wheat. All the specimens in the lot were found to be *T. madens*.

MATERIALS INFESTED

The flour beetles are known to attack such a wide variety of foods that they can be said to be practically omnivorous. They have been found feeding in over 100 different foodstuffs. The list comprises mainly grain and seeds of various kinds, flour, meal, and other cereal products, but also includes animal matter, wood, vegetables, and various drugs and spices.

FLOUR

Flour is the material principally infested by *Tribolium*. Practically any kind of flour may be infested, and whole-wheat flour seems especially liable to attack. The flour beetles have been considered second to the Mediterranean flour moth in the damage done in flour mills but at present are undoubtedly the most abundant and injurious insects found in such situations. However, they are usually less of an annoyance than the moth to millers because they do not spin webs that clog up the pipes and machinery. Where these pests are present in numbers the flour becomes grayish and discolored and will mold more quickly than clean flour. Sometimes the disagreeable, pungent odor given off by the scent glands is imparted to the flour, giving it a disgusting taste and odor.

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OTHER CEREAL PRODUCTS

Meal and many other ground products of grain are favored foods, and practically any kind of commercial breakfast food, stale bread, cakes, and cornstarch and other starches may be found to contain these pests. They often become very annoying in grocery stores, and if they become abundant they will get into every article of food in the place, sometimes almost ruining the merchant's business until he thoroughly fumigates the entire store. They are among the worst of pests on ships carrying edible produce of any kind because they will breed continuously and infest practically every foodstuff on board.

GRAIN AND OTHER SEEDS

The species of *Tribolium* cannot feed on entire, undamaged grain because their mandibles are not strong enough to chew through the tough outer coating. Practically all lots of grain, however, contain a certain percentage of broken kernels, so these beetles may be found infesing almost every known kind of grain. They are very common in grain shipments, usually occurring with either *Sitophilus* or *Rhizopertha*, at first more or less in the role of scavengers, but as the grain becomes more and more damaged they are able to do considerable injury of their own accord.

Grain waste and cracked grain products such as chicken feed are especially liable to attack. Quaintance reported corn in the field as attacked by *Tribolium castaneum*, but of this the writer is inclined to be very doubtful.

Excepting the grains, peas and beans of all kinds seem to be the seeds most commonly attacked. Cacao beans are often infested, and several instances of injury to cottonseed have been reported. There are many scattered references concerning injury to various seeds, and it seems likely that *Tribolium* will feed on practically any kind of seed, the only prerequisite being that some of the seeds be cracked or otherwise damaged.

NUTS

Although these insects are unable to penetrate the shells of most nuts, they will readily breed in any kind of cracked nuts and nut kernels. Persian (English) walnuts seem to be a favorite food, and peanuts are often infested and instances of serious damage to them have been reported (fig. 12, *A*).

DRIED FRUITS

Dried fruits of various kinds are often infested, but these flour beetles can hardly be said to be a major pest in such products. However, they occasionally do serious damage to raisins.

FOREST PRODUCTS

Since, as has already been shown, the original habitat of *Tribolium* appears to have been in rotting logs and under bark, it seems natural that all species of the genus should occasionally be found there at present. There are quite a number of references showing them to

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have been bred from various trees, especially from ash and pine. It seems probable, however, that they act as scavengers in such situations and do not feed on the wood itself. They have also been recorded from slippery elm and from resin, and the writer has observed that they sometimes riddle corks in the laboratory (fig. 13). Experiments on slippery elm and on cork indicate that they are unable to subsist on these products alone but use them only as auxiliary foods. It seems very unlikely that they could breed in resin.

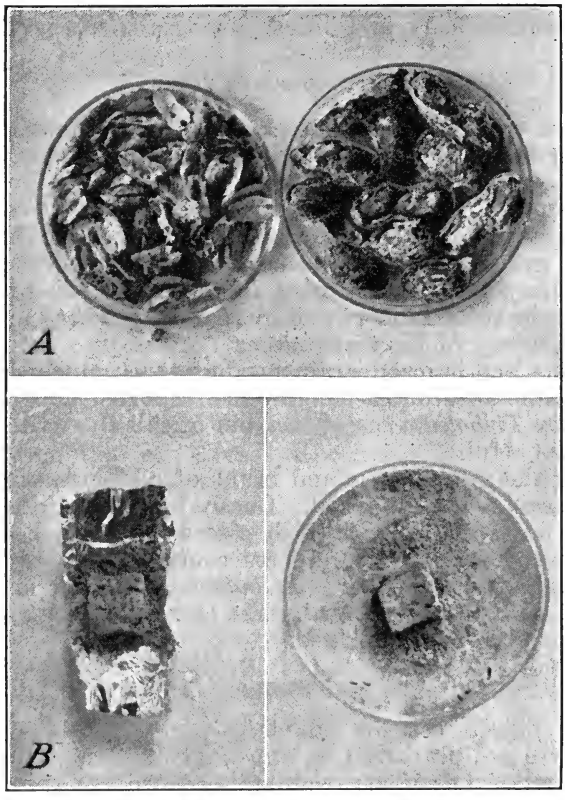

FIGURE 12.—Damage to foodstuffs by flour beetles: *A*, Peanuts infested by *Tribolium castaneum* following slight preliminary damage by *Plodia interpunctella*; *B*, adults of *T. confusum* feeding in a yeast cake.

SPICES

Several kinds of spices are attacked by the flour beetles. The writer was able to breed *T. confusum* in cayenne pepper with some difficulty and found that they would feed and survive for months on nutmeg and ginger. They have also been reported as feeding in mustard and cinnamon.

OTHER PLANT PRODUCTS

These beetles have been reported in snuff and orris root, and the writer's experiments indicate that they are able to breed in both of

these products. Baking powder is an acceptable food. They will also survive for some time on brown sugar but will not breed in it.

The beetles have several times been reported as feeding on yams, garlic, and other vegetables, but there are no records of their having been bred from these products. Herbarium specimens frequently suffer from their attacks. There are a few records of feeding on cured tobacco and dried cornstalks, but there seems to be no danger that these beetles will become a pest in tobacco.

They seem to have a liking for milk chocolate and will readily breed in it. However, this commodity tends to become sticky during hot weather, especially in the presence of the beetles, and they easily become entangled and perish. The writer has observed them breeding in yeast cakes in large numbers (fig. 12, *B*). Although no other food but the yeast was available, the beetles were exceptionally large and active, indicating that yeast provides a very satisfactory food.

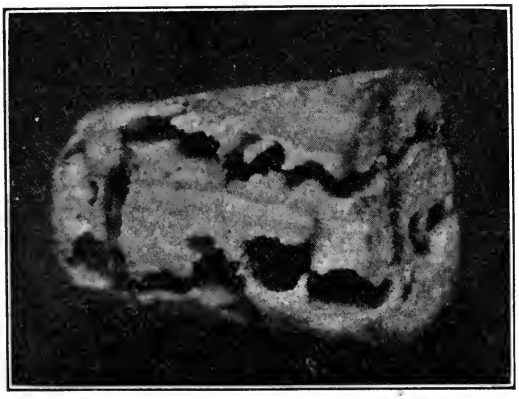

FIGURE 13. — A small cork riddled by *Tribolium confusum*, × 3.

ANIMAL MATTER

In insect collections *Tribolium* may do as much damage as the dermestids, and collectors must be continually on the lookout for their depredations. Although they cannot climb glass or smooth metal containers they can easily climb an insect pin, apparently by clutching the pin with their claws, and thus reach the mounted specimens. Hides and bird skins often become infested and ruined by these little pests. One record reports feeding on hog's bladder. Although not normally predacious, they have been observed to attack *Ephestia* larvae. However, it is doubtful whether this is of frequent occurrence, and experiments by the writer indicate that only the dying or diseased *Ephestia* larvae are subject to such attacks. Reports from India show that they also feed on lac. They have been found in the cells of bees in Hawaii but undoubtedly fed only on the pollen and did not otherwise molest the bees. Dried buttermilk and milk powder have been shown to be very satisfactory foods for these beetles.

LIFE HISTORY OF TRIBOLIUM CASTANEUM AND T. CONFUSUM

THE EGG

The eggs of *Tribolium confusum* (fig. 14) are oblong in shape, averaging 0.60 mm in length by 0.35 mm in width. The eggs of *T. castaneum* are indistinguishable from those of *T. confusum*. The eggs of both species are whitish or colorless and nearly transparent,

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The shell is smooth, unmarked, rather thin and pliable, and is covered with a sticky substance that aids in attaching the eggs to surfaces and causes small particles to adhere to them. Thus, eggs which are laid in flour or other finely ground substances are almost invariably coated more or less thickly. This makes it very difficult to detect the eggs in flour.

The eggs are placed directly in the flour or other foodstuff in which the adult is living. They may lie free in the flour or be attached to the surface of the container. The adults have usually been said to lay their eggs in cracks and crevices, but observations indicate that they show little preference for such places, the presence of food being the main consideration, and the eggs are placed anywhere in the food material.

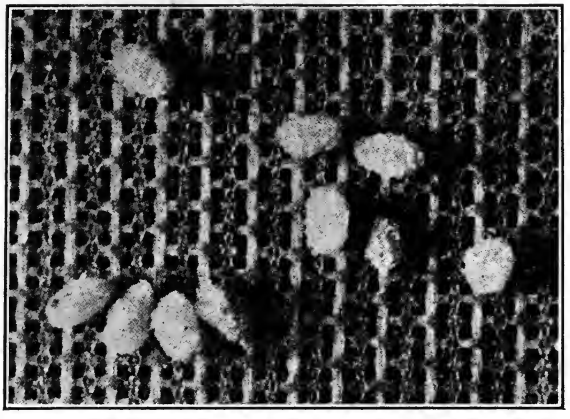

FIGURE 14.—Eggs of *Tribolium confusum* on no. 10 XX silk bolting cloth, × 16. (Dean.)

INCUBATION PERIOD

Since external conditions have a very marked influence on the incubation period of most eggs, various conditions of temperature, humidity, and light were experimented with in order that the duration of the egg stage under different conditions might be determined. The majority of these experiments were made with eggs of *T. castaneum*. Eggs of this species placed outdoors in November in Washington, D. C., at temperatures ranging upwards from only slightly above freezing all failed to hatch. Other eggs placed in a refrigerator at 6° C. failed to hatch. No constant temperatures between 6° and 25° were available so neither the killing point nor the minimum incubation temperature is known. Eggs kept at 35° likewise failed to hatch, while at 32° mortality was high but development rapid. Thirty degrees seems to be close to the optimum incubation temperature for eggs of this species. A lot of 137 eggs kept at this temperature hatched in from 3 to 5 days, with an average of 4 days. The records of some of these are shown in table 6. At 27° eggs hatched in a period averaging 5.2 days (table 3) and at 25° the period was from 5 to 7 days, averaging 6 days (table 5). Thirty-one eggs kept at room temperature in April required an average of 8.8 days to

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hatch (table 4). Here the temperature ranged from 18.5° to 28.5° and averaged 22° while the humidity ranged from 22 to 43 percent and averaged 32 percent. Twelve eggs kept at room conditions in November required 8 to 11 days with an average of 10 days. Here the temperature ranged from 18° to 29° and averaged 24°, while the relative humidity ranged from 27 to 47 percent and averaged 36 percent. All these experiments were carried on in continuous darkness to eliminate the variable factor of daylight. Continuous light slightly accelerates development.

The incubation period for *T. confusum* seems to be slightly longer than for *T. castaneum*. At 27° C. 37 eggs hatched in an average period of 6.8 days. The effect of light was tested in this case. Seventeen of these eggs were kept in continuous light and 20 were kept in continuous darkness. Those in continuous light had an average incubation period of 6.5 days, while those in continuous darkness required an average period of 7 days. An average of 12.8 days was required for the hatching of 40 eggs kept where the temperature averaged 21° and the relative humidity averaged 34 percent.

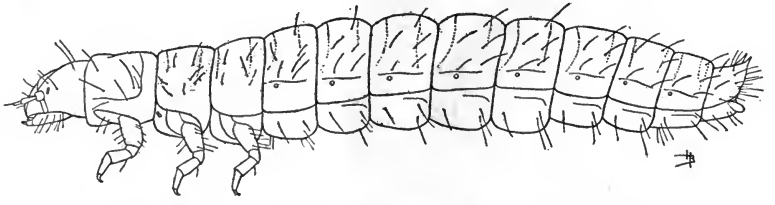

FIGURE 15.—*Tribolium castaneum:* Mature larva, × 20.

PERCENTAGE OF VIABLE EGGS

Records on the hatching of several hundred eggs show that under favorable conditions approximately 90 percent of the eggs laid by young females will hatch. Very old females may lay infertile eggs for considerable periods, sometimes months, before oviposition finally ceases.

THE LARVA

GENERAL DESCRIPTION OF MATURE LARVAE AND CHARACTERIZATION OF THE GENUS TRIBOLIUM MACL.[4]

Length, 6 to 7 mm; color mostly white, tinged with yellow, with dorsal part of head capsule, tips of claws, and terga of all segments slightly darkened, urogomphi and tips of mandibles testaceous. Form elongate cylindrical, about eight times as long as wide; dorsally convex, ventrally slightly flattened; ninth abdominal segment subquadrate in shape, bicornute; head and terga of all segments clothed with yellowish tactile hairs; body provided with a few long, thin, yellowish setae, those on ninth abdominal segment more numerous. Dorsal half of head capsule convex, not punctate, frontal angle not raised or produced. Ocelli, represented by two transverse groups of pigmented opthhalmic spots on each side of head, sometimes indistinct. Antennal articles with first slightly longer than wide; second about twice as long as wide, nearly twice as long as first article, distally bearing a minute supplementary appendix; third (apical article) small, elongate, cylindrical, about as long as first. Clypeus bearing two setae near each side margin. Labrum without transverse elevation or

[4] By R. A. St. George; based on larvae of *Tribolium castaneum* Hbst. and *T. confusum* J. du V. in the collection of the U. S. National Museum.

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series of spines across median area, the latter provided with two prominent setae each side; along antero-lateral margin ventrically, three short spinelike setae. Mandibles of right and left sides differing in shape slightly; both apically bifid, each with an additional tooth along dorsal margin of cutting edge between apex and molar part; tooth of right mandible placed near apex, that of left near molar part; ventrally with cutting edge deeply excavated; exterior surface distally rounded, proximally slightly excavated, without membranous elevation and without tubercle near fossa; usually bearing three setae on dorsal side, one placed distally about midway between apex and fossa, one placed proximally near fossa, and the other usually placed about equidistant between them. Epipharynx with minute paired hooks on soft-skinned portion. Hypopharyngeal sclerome absent, region membranous. Prothoracic legs only slightly larger than mesothoracic and metathoracic pairs. Spiracles annular, with circular mouth piece. Ninth abdominal segment distinctly shorter than eighth wider than long; urogomphi directed upward and backward (not hoop shaped); side margins without short spinelike setae; ninth sternum bearing a few setae. Anal pseudopods distinct, quite long, cylindrical in shape.

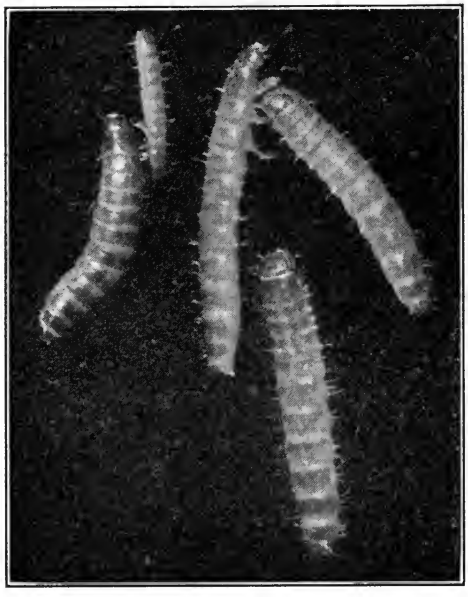

FIGURE 16.—Larvae of *Tribolium confusum*: The small one is a third-instar larva, the others are sixth-instar larvae, × 8.

FIELD IDENTIFICATION

The larvae of *Tribolium* may be readily distinguished from the somewhat similar appearing larvae of *Gnathocerus*, *Palorus*, or *Alphitobius* by the prominent two-pointed or forked termination of the last body segment (figs. 15 and 16). In each of the other genera mentioned, the body terminates caudally in a single point. In *Tenebrio* there is a small fork, somewhat intermediate between that of *Tribolium* and the single-pointed termination of *Gnathocerus*, etc.

NUMBER OF LARVAL INSTARS

Actual counts of the number of larval instars in *T. confusum* have previously been made by Chapman and by Brindley. Chapman (*17*) gives the idea that there are always 6 instars, but later shows that external conditions, especially food, may increase this number to as many as 12. In order to determine the exact number of larval instars, the writer placed eggs of both species of *Tribolium* in separate small vials and observed them each day until the individuals emerged as adults. One hundred and thirty individuals were thus observed. Various conditions of temperature, humidity, and food were covered in these tests. After each molt the exuviae were removed and recorded. Through these observations the writer has determined that there is no fixed number of larval instars, the number ranging from 5 to 11 or more, and that the usual number is 7 or 8 instead of 6. This

variation is due to both external conditions, such as food, temperature, humidity, etc., and to individual characteristics entirely apart from external influence.

DURATION OF THE LARVAL INSTARS

Detailed results of the work on the life cycle of *Tribolium* are given in tables 2, 3, 4, 5, and 6. As shown in these tables, the larval period ranges from 22 to over 100 days, according to the temperature and food. The period for *T. confusum* is somewhat longer than for *T. castaneum*. The optimum temperature for the development appears to be 30° C. for both species. Growth is rapid in such foods as whole-wheat flour, middlings, bran, and corn meal, but very slow in white flour.

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TABLE 2.—*Developmental data on Tribolium confusum at 27° C.*

Individual no.	Length of egg stage	Duration of larval instars [1]										Length of larval period	Length of pupal period	Length of developmental period	Sex	Kept in light (L) or darkness (D)	Food
		First	Second	Third	Fourth	Fifth	Sixth	Seventh	Eighth	Ninth	Last						
	Days	*Days*	*Days*	*Days*	*Days*	*Days*	*Days*	*Days*	*Days*	*Days*	*Days*	*Days*	*Days*	*Days*			
1	6	1½	4	4	5	5	5				7	31	8	45	Male	D	Middlings.
2	8	1½	4½	4	4	4	4				8	30	7	45	Female	D	Do.
3	8	1½	4½	4	4	4	4	5			5	32	7	47	do	D	Do.
4	6	2	5	4	4	5	5				6	31	9	46	Male	L	Do.
5	5	1½	4	5	4	5	6				8	33	8	46	do	D	Bran.
6	7	3	4	5	5	6	7				6	36	8	51	Female	D	Do.
7	8	2	5	5	4	5	5				9	35	9	52	do	D	Do.
8	6	2	4	5	5	6	6	6			6	40	8	54	do	D	Do.
9	7	3	5	6	5	6	5	4			6	40	9	56	do	D	Do.
10	7	2	6	5	5	9	8				8	43	9	59	do	L	Do.
11	8	4	4	5	6	6	6	6			7	44	9	61	do	D	Do.
12	8	1½	4½	8	7	8	10	7			7	53	9	70	do	D	Do.
13	7	2	13	7	7	7	5	5			9	55	10	72	Male	L	Do.
14	8	1½	8	14	13	5	5	5			9	60	9	77	Female	D	Do.
15	8	1½	5½	7	9	8	8	10	7		8	64	8	80	do	D	Do.
16	6	1½	5	8	8	6	7	8			9	52	8	66	Male	D	Oatmeal.
17	7	2	4	6	8	6	7	8			9	50	9	66	Female	L	Do.
18	5	1½	7	6	8	8	7	8			10	55	9	69	Male	D	Do.
19	8	3	8	6	8	7	8	8			11	59	9	76	do	L	Do.
20	7	2	5	8	9	13	37	10	8	8	7	107	6	120	do	L	Do.
21	8	1½	4½	6	7	8	18	25			19	89	8	105	do	D	White flour.
22	8	2	4	21	10	40					35	112	9	129	do	D	Do.
23	7	3	4	5	5	6	8	9			25	65	(2)		do	D	Do.
24	7	2	5	6	7	9	15	10	15	(2)						D	Do.
25	7	2	6	6	8	7	10	13	(2)							L	Do.
26	6	2	5	5	8	9	16	14	(2)							L	Do.
27	8	2	5	6	9	10	16	(2)								D	Do.
28	8	1½	5½	5	5	7	14	(2)								D	Do.

[1] The fractions are approximate, and the full larval periods have been rounded to whole days.

[2] Died.

TABLE 3.—*Developmental data on Tribolium castaneum at 27° C.*

Individual no.	Length of egg stage	Duration of larval instars										Length of larval period	Length of pupal period	Length of developmental period	Sex	Food
		First	Second	Third	Fourth	Fifth	Sixth	Seventh	Eighth	Ninth	Last					
	Days	*Days*	*Days*	*Days*	*Days*	*Days*	*Days*	*Days*	*Days*	*Days*	*Days*	*Days*	*Days*	*Days*		
1	5	2	4	4	3	3					6	22	7	34	Male	Middlings.
2	5	2	4	4	3	3					7	23	7	35	do	Do.
3	5	2	4	4	3	4					7	24	7	36	Female	Do.
4	5	2	4	4	5	5	5				8	33	7	45	do	Do.
5	5	2	5	5	4	5	6	7			6	40	8	53	Male	Do.
6	5	2	7	4	5	5	5	7			8	43	8	56	Female	Do.
7	5	2	6	5	5	5	6	6			8	43	8	56	do	Do.
8	6	2	4	3	4	4					7	24	7	37	Male	Bran.
9	5	2	4	4	4	4					8	26	7	38	do	Do.
10	5	2	4	4	4	4					8	26	7	38	do	Do.
11	5	2	4	4	4	4	5				5	28	8	41	Female	Do.
12	5	2	4	4	4	4	5				7	30	8	43	do	Do.
13	6	2	5	4	5	4	5				7	32	8	46	Male	Do.
14	6	2	6	5	4	5	5				9	36	8	50	Female	Do.
15	5	2	6	3	3	4	5				6	29	7	41	do	Whole-wheat flour.
16	6	2	4	4	4	4	4				6	28	7	41	Male	Do.
17	6	1	4	4	4	4	5				6	28	7	41	Female	Do.
18	6	2	4	4	3	4	5				6	28	8	42	Male	Do.
19	6	1	4	4	4	4	5				6	28	8	42	Female	Do.
20	5	2	4	4	4	5	4				7	30	8	43	Male	Do.
21	5	2	4	5	7	5	6	6			7	42	9	56	Female	Do.
22	5	2	4	4	3	4					8	25	7	37	Male	Corn meal.
23	5	2	4	4	3	4					8	25	7	37	Female	Do.
24	5	2	4	4	3	5	4				6	28	7	40	Male	Do.
25	5	2	4	4	4	4	5				7	30	8	43	do	Do.
26	6	2	4	4	5	4	4				7	30	7	43	Female	Do.
27	6	2	5	5	4	5					8	29	8	43	Male	Do.
28	5	2	6	6	4	4	5				8	35	8	48	Female	Do.
29	6	2	6	9	6	6	7	10			7	53	7	66	Male	Do.
30	5	2	6	6	6	6	7	6	9		6	54	7	66	do	Oatmeal.
31	5	2	5	4	4	10	7	12			18	62	6	73	do	Do.
32	5	2	5	7	10	10	14	13			6	67	6	78	Female	Do.
33	5	1	6	8	10	15	12	9	9	11	9	90	7	102	Male	Do.
34	5	2	6	7	8	6	6	7	12	(1)						Do.
35	5	2	6	17	17	15	10	10	10	(1)						Do.
36	5	2	5	6	7	12	22	(1)								White flour.
37	5	2	5	5	10	20					31	73	7	85	Male	Do.
38	5	2	5	5	8	11	15	17	26		14	103	6	114	do	Do.
39	5	2	6	6	6	13	19	(1)								Do.
40	5	2	6	8	8	11	(1)									Do.
41	5	2	5	5	8	28	(1)									Do.
42	5	2	6	6	18	25	(1)									Do.
43	5	2	6	6	8	(1)										Do.

[1] Dead.

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TABLE 4.—*Data on development of Tribolium castaneum at room temperatures in Washington, D. C., in 1930*

Individual no.	Date egg laid	Date egg hatched	Incubation period	Date of first molt	Length of first instar	Date of second molt	Length of second instar	Date of third molt	Length of third instar	Date of fourth molt	Length of fourth instar	Date of fifth molt	Length of fifth instar	Date of sixth molt	Length of sixth instar	Date of seventh molt
			Days		*Days*		*Days*		*Days*		*Days*		*Days*		*Days*	
1	Apr. 1	Apr. 10	9	Apr. 12	2	Apr. 20	8	Apr. 27	7	May 2	5	May 7	5	May 13	6	
2	do	do	9	Apr. 13	3	do	7	do	7	do	5	do	5	do	6	
3	do	do	9	do	3	Apr. 23	10	Apr. 29	6	May 4	5	May 9	5	May 14	5	
4	Apr. 2	Apr. 11	9	Apr. 14	3	Apr. 26	12	May 2	6	May 8	6	May 14	6	May 21	7	June 1
5	do	do	9	Apr. 13	2	Apr. 21	8	Apr. 27	6	May 2	5	May 6	4	May 10	4	
6	do	do	9	do	2	Apr. 20	7	Apr. 26	6	May 1	5	do	5	----------	----------	
7	do	do	9	do	2	Apr. 21	8	Apr. 27	6	May 2	5	May 7	5	May 12	5	
8	do	do	9	do	2	do	8	Apr. 28	7	do	4	May 6	4	May 14	8	
9	do	do	9	do	2	Apr. 22	9	Apr. 29	7	May 4	5	May 9	5	May 15	6	May 23
10	do	do	9	Apr. 14	3	Apr. 23	9	Apr. 30	7	May 5	5	do	4	May 13	4	May 21
11	do	do	9	Apr. 13	2	Apr. 22	9	do	8	May 6	6	May 11	5	May 20	9	June 3
12	do	do	9	do	2	Apr. 24	11	May 6	12	May 13	7	May 23	10	June 3	11	June 11
13	do	do	9	do	2	do	11	Apr. 30	6	May 5	5	May 11	6	May 17	6	May 26
14	do	do	9	do	2	Apr. 25	12	May 3	8	May 9	6	May 17	8	May 26	9	June 3
15	Apr. 3	do	8	Apr. 14	3	Apr. 29	15	May 7	8	May 14	7	May 22	8	June 2	11	June 8
16	do	Apr. 12	9	Apr. 15	3	Apr. 27	12	May 6	9	do	8	do	8	June 1	10	Do.
17	Apr. 2	do	10	Apr. 16	4	Apr. 22	6	Apr. 29	7	May 4	5	May 9	5	May 17	8	
18	Apr. 3	Apr. 11	8	Apr. 13	2	Apr. 21	8	Apr. 27	6	May 2	5	May 6	4	----------	----------	
19	do	do	8	Apr. 14	3	do	7	do	6	do	5	May 7	5	May 14	7	
20	do	do	8	do	3	Apr. 22	8	Apr. 28	6	May 3	5	May 8	5	----------	----------	
21	do	Apr. 12	9	do	2	Apr. 21	7	Apr. 27	6	May 1	4	May 5	4	----------	----------	
22	do	do	9	do	2	do	7	do	6	May 2	5	May 6	4	----------	----------	
23	do	do	9	do	2	do	7	do	6	do	5	May 7	5	May 12	5	
24	do	do	9	do	2	Apr. 23	9	Apr. 29	6	May 4	5	May 9	5	May 14	5	May 24
25	Apr. 4	do	8	do	2	do	9	May 2	9	May 9	7	May 20	11	June 3	14	June 14
26	do	do	8	Apr. 15	3	Apr. 25	10	May 4	9	May 13	9	May 28	15	June 11	14	June 18
27	do	Apr. 13	9	Apr. 16	3	Apr. 27	11	May 15	18	June 2	18	June 14	12	June 22	8	June 29
28	do	Apr. 12	8	Apr. 14	2	Apr. 22	8	Apr. 29	7	May 7	8	May 28	21	June 21	21	July 3
29	do	do	8	Apr. 15	3	Apr. 24	9	May 5	11	May 30	25	June 25	26	July 22	27	
30	do	Apr. 13	9	do	2	Apr. 23	8	May 2	9	May 11	9	June 5	25	June 24	19	
31	do	do	9	do	2	Apr. 24	9	May 5	11	May 20	15	June 3	14	June 15	12	June 29

Individual no.	Length of seventh instar	Date of eighth molt	Length of eighth instar	Date of ninth molt	Length of ninth instar	Date of tenth molt	Length of tenth instar	Date of pupation	Length of last instar	Length of larval period	Date adult emerged	Length of pupal period	Length of developmental period	Food	Sex
	Days		*Days*		*Days*		*Days*		*Days*	*Days*		*Days*	*Days*		
1								May 24	11	44	June 5	12	65	Bran	Male.
2								May 28	15	48	June 7	10	67	do	Female.
3								May 27	13	47	do	11	67	do	Do.
4	11	June 7	6					June 18	11	68	June 26	8	85	do	Male.
5								May 22	12	41	June 3	12	62	Whole-wheat flour	Do.
6								do	16	41	do	12	62	do	Female.
7								May 24	12	43	June 5	12	64	do	Male.
8								May 29	15	48	June 8	10	67	do	Female.
9	8							June 5	13	55	June 14	9	73	do	Do.
10	8							June 3	13	53	June 11	8	70	do	Do.
11	14							June 18	15	68	June 25	7	84	Corn meal	Male.
12	8							do	7	68	do	7	84	do	Female.
13	9							June 12	17	62	June 19	7	78	do	Do.
14	8							June 11	8	61	do	8	78	do	Male.
15	6	June 14	6					June 23	9	73	June 29	6	87	do	Female.
16	7							June 19	11	68	June 25	6	83	do	Do.
17								June 5	19	54	June 14	9	73	do	Male.
18								May 15	9	34	May 27	12	54	Middlings	Do.
19								June 1	18	51	June 9	8	67	do	Do.
20								May 19	11	38	June 1	13	59	do	Female.
21								May 12	7	30	May 23	11	50	do	Do.
22								May 15	9	33	May 26	11	53	do	Male.
23								May 23	11	41	June 4	12	62	do	Do.
24	10							June 7	14	56	June 15	8	73	do	Female.
25	11	June 24	10	July 7	13	July 21	14	Aug. 20	30	130				Oatmeal	Male.
26	7	June 26	8	July 4	8	July 14	10	July 23	9	102	July 28	5	115	do	Do.
27	7	July 5	6	July 12	7	July 23	11	Aug. 1	9	110	Aug. 6	5	124	do	Do.
28	12	July 26	23	Aug. 2	(1)									White flour	
29								Aug. 5	14	115	Aug. 10	5	128	do	Female.
30								July 10	16	88	July 18	8	105	do	Male.
31	14	July 18	19					Aug. 7	20	116	Aug. 13	6	131	do	Female.

[1] Dead.

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TABLE 5.—*Data on developmental period of Tribolium castaneum at 25° C. in whole-wheat flour*

Individual no.	Length of egg stage	Duration of larval instars [1]									Length of larval period	Length of pupal period	Length of period from egg to adult	Sex
		First	Second	Third	Fourth	Fifth	Sixth	Seventh	Eighth	Last				
	Days	*Days*	*Days*	*Days*	*Days*	*Days*	*Days*	*Days*	*Days*	*Days*	*Days*	*Days*	*Days*	
1	7	2	6	4	6	5	7	-----	-----	8	38	8	53	Male.
2	7	1¾	6	4¼	5	6	8	-----	-----	11	42	8	57	Female.
3	5	2	7	3	5	5	10	-----	-----	12	44	10	59	Do.
4	5	2	6¾	3¼	6	6	8¼	-----	-----	13	45	9	59	Do.
5	7	1¼	6	4	6	6	7	-----	-----	12	42	13	62	Do.
6	6	2	5¾	4½	7	5	8	8	5	9	54	6	66	Do.
7	6	2	6	4	5	6	10	9	-----	11	53	7	66	Male.
8	6	2	8	4¼	7	6	6	7	5	9	54	6	66	Do.
9	6	1½	6	4	7	5	8	7	-----	15	53	7	66	Do.
10	6	2	7½	4½	6	7	8	8	-----	12	55	6	67	Do.
11	6	2	7	5	5	7	9	-----	-----	26	61	9	76	Female.

[1] The fractions are approximate, and the full larval periods have been rounded to whole days.

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TABLE 6.—*Data on development of Tribolium castaneum at 30° C.*

Individual no.	Length of egg stage	Duration of larval instars [1]												Length of larval period	Length of pupal period	Length of developmental period	Sex	Food
		First	Second	Third	Fourth	Fifth	Sixth	Seventh	Eighth	Ninth	Tenth	Eleventh	Last					
	Days	*Days*	*Days*	*Days*	*Days*	*Days*	*Days*	*Days*	*Days*	*Days*	*Days*	*Days*	*Days*	*Days*	*Days*	*Days*		
1	4	2	2	4½	1¾	4	4						4	22	5½	32	Female	Corn meal.
2	4	1	5	4	2½	3½	3						3	22	5½	32	do	Do.
3	4	1	5¾	3	3	3	3						5	24	4	32	do	Do.
4	4	1	5¼	3½	2½	2½	5¾						4½	25	4	33	Male	Do.
5	4	1	5	2¾	4	3	3¾						8½	28	4½	36	do	Precooked wheat cereal.
6	4	1	6¾	4½	1¾	3¼	3¼	8½	15¼	11	11	31	[2] 16					Do.
7	4	2	6	4½	2¼	3½	5	6	11¼	19	18	[3] 19						Do.
8	4	2	4	3	4	3	5	12	[4] 14									Do.
9	4	1	6½	5	3¾	7	5½	[4] 8½										Do.
10	4	1½	6¼	5¼	2¾	3	4						5	28	4	36	Male	Dog biscuit.
11	4	1	7½	3½	1½	2	3	3					4	26	4½	34	do	Do.
12	5½	2	4½	7¼	3½	2¼							6	26	6	37	do	Do.
13	4	1½	5¾	4½	3¾	3¾	5	11					14	49	6	59	do	Pancake flour.
14	4	2	5	5¼	4	3½	5	11					16	52	6	62	do	Do.
15	4	1	7¾	4	4	3	5	8	10	5			5	53	6	63	do	Do.
16	4	1	5	5½	3¾	3	3¾	12	11	9			9	63	4	71	Female	Do.
17	4	2	6	5	4	4½	5	10½	11	7			12	67	6	77	do	Do.
18	4	1¾	5½	4¼	3¾	4	7¾	11	7	9	10		14	78	6	88	do	Do.
19	4	1	6¾	9	3	5	8	9¾	7½	11	13	16	7	97	6	107	do	Do.
20	4	1½	9	4¼	[5] 7¼													Red pepper.
21	4½	1½	6¼	5¾	[5] 4													Do.
22	4	1¾	4¼	4½	2½	3	4						6	26	4	34	Male	Oatmeal.
23	4	1¾	5¾	4¼	3	3							8	26	4	34	do	Do.
24	4	1½	5½	4	2¾	2¾	4¼						8	29	4	37	Female	Do.
25	4½	1¾	5	4	3	3¾							17	35	5	44	Male	Do.
26	4	1½	14½	4¾	3	6	6	7	10				13	66	6	76	Female	Do.
27	4½	1½	5¾	4¼	8	17	25	10	8	14	10	[6] 19						Do.
28	4½	1½	5¾	7	3	4	8	4					7	40	5	50	Female	Rye flour.
29	4	1¾	5	8	4	6							47	72	5	81	Male	Do.
30	4	1¾	5	4¼	3½	4¼	[3] 6											Do.
31	4	1½	3¾	5¾	6								5	22	4	30	Male	Whole-wheat flour.
32	4	1½	3½	4½	6	4							3	22	4	30	do	Do.
33	4	1½	4¼	3½	6								7	22	6	32	Female	Do.
34	5	1½	4¼	3¼	2¾	3¾	3						6	24	5	34	do	Do.
35	5	1½	4	3½	3¾	3	3						5	24	5	34	do	Do.
36	4	1½	5½	2½	4¼	3¼	4						6	27	5	36	Male	Do.

[1] The fractions are approximate, and the full larval periods have been rounded to whole days.
[2] Died Mar. 10.
[3] Died Feb. 11.
[4] Died Jan. 6.
[5] Died Dec. 3.
[6] Dead Mar. 12.

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WIDTH OF THE HEAD CAPSULE

It was found possible to determine accurately the instar of a larva by measuring the width of the head capsule. There is considerable individual variation but practically no overlapping of the measurements of an individual of one stage with those of the next until after the sixth instar. The figures for *T. confusum* in table 7 will be found to differ from those of Chapman (*17*) and Brindley (*12*), both of whom based their data on larvae which completed their development in six instars.

TABLE 7.—*Measurements of Tribolium confusum*

Stage	Instar	Specimens measured	Body						Head capsule width			
			Length			Width						
			Maximum	Minimum	Average	Maximum	Minimum	Average	Maximum	Minimum	Average	Increase
		Number	*Mm*	*Mm*	*Mm*	*Mm*	*Mm*	*Mm*	*Mm*	*Mm*	*Mm*	*Mm*
Egg		40	0.690	0.476	0.601	0.400	0.257	0.355				
Larva	First	50	1.260	.863	1.113	.268	.193	.236	0.196	0.150	0.175	
Do	Second	45	1.828	1.220	1.490	.298	.223	.254	.213	.178	.197	0.022
Do	Third	34	2.514	1.607	1.918	.387	.268	.308	.268	.236	.249	.052
Do	Fourth	30	3.182	1.886	2.379	.447	.327	.368	.357	.277	.311	.062
Do	Fifth	22	3.818	2.273	3.044	.536	.417	.456	.420	.327	.378	.067
Do	Sixth	21	4.364	3.000	3.496	.658	.417	.524	.568	.417	.459	.081
Do	Seventh	13	5.091	4.091	4.643	.833	.655	.715	.655	.476	.585	.126
Do	Eighth	5	6.363	4.364	5.153	.953	.655	.846	.685	.536	.619	.034
Do	Ninth	3	5.818	5.363	5.545	.953	.804	.893	.714	.565	.655	.036
Pupa		18	3.818	3.000	3.369	1.280	1.012	1.132	.863	.729	.795	
Adult		16	3.820	3.090	3.475	1.260	1.080	1.169	.800	.700	.743	

HABITS

The larvae of *Tribolium* are fairly active and may be found in any of the foods listed under the heading Materials Infested. They usually shun the light and live more or less concealed in the food, in which they bury themselves if disturbed. In flour mills and warehouses they may often be found in cracks and in dark places, but more often they live directly in a quantity of flour or meal, feeding near the surface or under any piece of paper, wood, or other material that may be placed on the surface.

THE PUPA

PUPATION

When fully grown, the larva comes to the surface of the material in which it has been feeding, or to some sheltered space or crack, and there the change to the pupa takes place. As with many Coleoptera, the pupa of *Tribolium* is naked and without protection of any kind (figs. 17 and 18). Vacated pupal cells of the Mediterranean flour moth are favorite places for pupation when they are available, several *Tribolium* pupae often being found in one cell. At first the pupa is entirely white, but within a day or two it acquires a yellowish tint which gradually turns darker. Likewise, the eyes soon turn black, and the claws and the tips of the mandibles and of the urogomphi turn to a dark brown.

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APPEARANCE OF THE PUPA

The eyes in *T. confusum* are nearly, but not completely, divided by the genae, while those in *T. castaneum* are only slightly emarginated. In both species the antennae, elytra, and legs are free but closely pressed against the body, the tips of the elytra reaching the middle of the fifth abdominal segment. The prothorax is rather thickly covered with short, stiff spines arising from tubercles. The front and side margins of the prothorax are fringed with setae; those along the side margins and the sides of the front margin are long, those near the center of the front margin much shorter.

The abdominal segments, excepting the eighth, ninth, and tenth, are provided laterally with characteristic irregular projections. In *T. confusum* these lateral processes are provided with 3 hairs, 1 rather long hair arising from the anterior lobe and 2 shorter hairs from very small median lobes. In *T. castaneum* 1 hair arises from the large anterior lobe and a shorter hair at a point one-third from the posterior serrate margin. The ninth segment is provided with 2 rather long urogomphi.

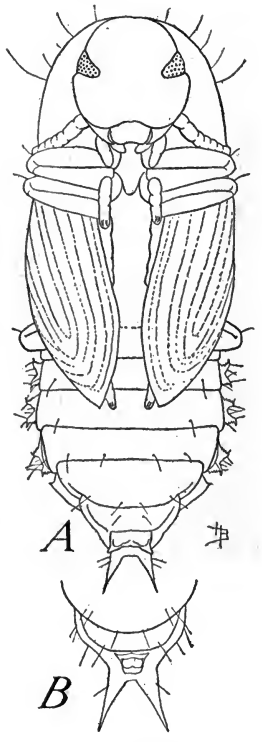

FIGURE 17. — Pupa of *Tribolium castaneum*: *A*, Female, × 20; *B*, terminal segments of a male pupa.

DIFFERENCE IN APPEARANCE BETWEEN MALES AND FEMALES

The appearance of the ventral surface of the terminal abdominal segment of the pupa differs greatly in the males and females. It is on this difference only that the sexes may be distinguished externally, since the appearance of the two sexes in the adult is identical. The form of the genital segment is shown in figure 17, *B*. The chief characteristic of this segment in the male is a flat disklike depression, whereas in the female two conelike appendages, similar in appearance to the urogomphi, but much shorter and relatively thicker, may be distinguished.

SEX RATIO

Of 800 individuals of *T. confusum* reared on whole-wheat flour at 30° C., 52 percent were females and 48 percent were males. Two hundred pupae of *T. castaneum* reared under similar conditions gave a sex ratio of 59 percent females and 41 percent males.

SIZE AND WEIGHT OF PUPAE

Measurements for *T. confusum* are given in table 7. Sixty pupae of *T. castaneum* averaged 3.35 mm in length, not including the urogomphi, and 1.17 mm in width through the elytra. Females averaged slightly larger than males. The head capsule widths of 35 individuals averaged 0.707 mm.

Six hundred and fifty pupae of *T. confusum* were weighed on an anylitical balance in lots of 50. Three hundred male pupae averaged

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2.13 mg each and 350 female pupae averaged 2.49 mg each. There appeared to be only slight variation in the size and weight of individuals. Of 125 pupae of *T. castaneum*, 53 males averaged 1.77 mg each, while 72 females averaged 1.89 mg each.

PUPAL PERIOD

The duration of the pupal period seems to be less affected by external conditions than that of the egg or larval periods. Records on the pupal period are given in tables 2, 3, 4, 5, and 6. Quite a few additional pupal records were obtained, and the summary of all pupae observed is as follows:

FIGURE 18.—Pupae of *Tribolium confusum*, × 7½.

Of pupae of *T. confusum* kept at 27° C., 31 kept in continuous darkness emerged as adults in from 7 to 12 days, with an average of 8.7 days; and 43 kept in continuous light emerged in from 6 to 9 days, with an average of 7.9 days. One hundred and twelve pupae of *T. castaneum* kept at 27°, for the most part in continuous darkness, had a pupal period of from 6 to 9 days, with an average of 7.14 days; and 28 kept at 30° emerged in from 4 to 6 days with an average of 5 days. Eleven kept at 25° emerged in from 6 to 12 days with an average of 8.8 days, and 32 kept at room temperature during the early summer had a period ranging from 5 to 14 days, averaging 8.5 days.

THE ADULT

Adults of both these species of *Tribolium* are small, reddish-brown beetles, about 3.5 mm in length, and with the elytra striated (figs. 2, 3, and 19). Superficially the two species are very much alike, but with the aid of a microscope the differences in the eyes and antennae readily separate them. In each species the sexes are identical externally and cannot be differentiated except by squeezing out the genitalia by a slight pressure on the abdomen.

FLIGHT

Both species have well-developed wings, but only *T. castaneum* has been observed to use them. This species is not a strong flier and flies only occasionally. In the laboratory the longest period during which it remained on the wing was approximately 20 seconds, but it seems probable that in the open it could stay in the air for somewhat longer

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periods. It could not fly from one flour mill to another unless the mills were very close together and the flight were aided by wind, but it could possibly fly from the hold of a ship to a pier. It has been seen to fly so seldom, however, it appears unlikely that an infestation would spread often in this manner. *T. confusum*, although possessing well-developed wings, has never been taken in flight, and attempts to induce it to fly have always failed.

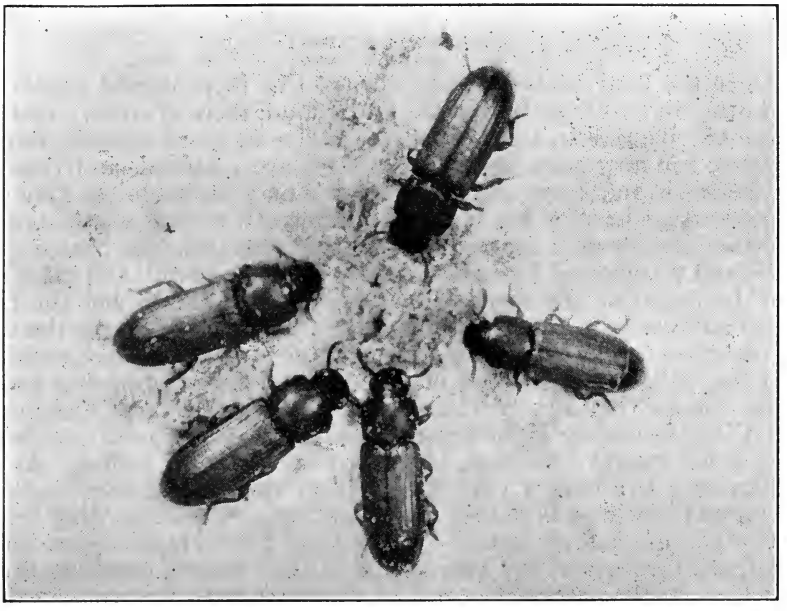

FIGURE 19.—Adults of *Tribolium confusum* feeding on flour, × 8½.

ACTIVITY

Adult flour beetles are rather active, quickly running to cover or burying themselves in the flour if disturbed. Ordinarily they live concealed in the flour or under any suitable object which may be near their food supply. They do not always try to hide themselves, however, and numbers may usually be found crawling around over flour or grain in mills or stores (fig. 19). They move about readily inside a building and soon infest every article of food in the place. Their small size and flat bodies enable them to force their way into all but the tightest boxes or containers.

EFFECT ON FLOUR

Light infestations of flour beetles usually would pass unnoticed except for the beetles themselves, as they seem to do less perceptible damage to their foodstuff than do most insects. But if the beetles are present in quantities, a certain discoloring of the flour takes place, and in time it turns to a dirty grayish mass.

SCENT GLANDS

The scent glands of these beetles are rather well developed and contain a vile-smelling fluid which is ejected as a means of defense, often imparting a disagreeable, pungent odor to the food. It is often released when the beetles are excited by the stirring up of the flour in which they are feeding, or when a beetle is crushed between the fingers. Functional scent glands are possessed by the adults of both species but not by the larvae.

SEASONAL HISTORY

Since the flour beetles nearly always live in protected situations, and often in buildings heated the year round, there is no very marked seasonal variation in their activity. When they are exposed to cold weather for long periods their activities are retarded, and those in the less resistant stages of their life cycle may succumb. It may also be noted that in very hot climates the insect's activities are speeded up, and life is much shorter than in cool climates. In heated flour mills and warehouses *Tribolium* breeds the year round, and all stages may be found at any time. In unheated mills this is not the case. Some authors have stated that these beetles do not live over the winter in unheated mills but die out with the coming of cold weather; and the mills are reinfested in the spring from neighboring heated mills. Inspection of several unheated mills in Maryland and northern Virginia during February revealed many adults of *T. confusum* in a semidormant condition, but no living larvae or pupae. As the adults may live over a year it is evident that in unheated mills in this area the winter is passed in the adult stage, and breeding begins with the approach of spring. In the Gulf States breeding probably continues throughout the year, while in the extreme northern States and Canada the species may not be able to survive the winter except in heated buildings. *T. castaneum* seems to be less resistant to cold than *T. confusum*.

LONGEVITY

The developmental stages of *Tribolium* are comparatively short, but the adult life is among the longest recorded for the stored-product insects. Previous estimates of the adult life have ranged from 3 months to a year, but the writer's observations on 25 pairs each of *T. confusum* and *T. castaneum*, which were used in oviposition experiments, and results from an experiment run for this specific purpose show that the maximum length of adult life may be over 3 years.

Early in 1930 an experiment was started in which 50 adults of *T. confusum* of known sex and usually of known parentage were segregated on emergence and examined periodically to determine the maximum length of life for this species. The beetles were put into 16 by 50 mm vials, lightly stoppered with cotton, and kept in darkened pasteboard boxes at room temperature. A variety of different foods was used. The numbers of these individuals decreased gradually, the mortality being somewhat greater during July and August of each year, owing, no doubt, to the excessive heat. The data on seven of these individuals that survived for more than 2 years and 11 months are given in table 8.

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TABLE 8.—*Some examples of extreme adult longevity in Tribolium confusum, Washington, D. C.*

Individual no.	Sex	Food	Date adult emerged	Date adult died	Adult age at death
			1930	1933	
1	Male	Whole-wheat flour	Jan. 27	Mar. 14	3 years, 46 days.
2	do	do	Feb. 7	Nov. 5	3 years, 271 days.
3	Female	do	Feb. 10	May 20	3 years, 99 days.
4	Male	do	Mar. 16	Apr. 5	3 years, 20 days.
5	Female	Oatmeal	Mar. 17	Apr. 3	3 years, 17 days.
6	do	Whole-wheat flour	Mar. 25	Mar. 7	2 years, 347 days.
7	Male	Oatmeal	May 10	Aug. 28	3 years, 110 days.

All the adults used in oviposition experiments were likewise segregated and examined periodically to determine the length of life of each. These were kept in smaller vials (11 by 40 mm) and under various conditions. Of the 25 pairs each of *T. confusum* and *T. castaneum*, 14 individuals survived for more than 2 years as shown in table 9.

TABLE 9.—*Adult life of 14 individuals of Tribolium, Washington, D. C.*

Tribolium confusum			*Tribolium castaneum*		
Pair no.	Sex	Adult life	Pair no.	Sex	Adult life
25	Male	3 years, 268 days	15	Male	2 years, 159 days.
21	do	2 years, 327 days	8	do	2 years, 154 days.
23	Female	2 years, 217 days	17	do	2 years, 86 days.
22	do	2 years, 212 days	9	do	2 years, 77 days.
13	Male	2 years, 189 days			
23	do	2 years, 169 days			
24	do	2 years, 153 days			
15	do	2 years, 96 days			
14	do	2 years, 69 days			
21	Female	2 years, 26 days			

It should be mentioned that each female in this case laid several hundred eggs, while those given in table 8 never mated. It is also interesting to note that all the individuals in the oviposition experiment that survived more than 2 years were fed on whole-wheat flour, although five other foods were used in the experiments. From these tables and other data it seems that *T. confusum* live somewhat longer than *T. castaneum* and likewise that males live somewhat longer than females.

From the life-history data of tables 10 and 11 it may be found that the average adult life of males of *T. confusum* is about 634 days, and of females, 447 days. For *T. castaneum* the average for males is 547 days, and for females, 226 days.

FERTILITY OF VERY OLD BEETLES

Experiments have proved not only that these beetles live to a comparatively great age but that males of *T. confusum* may be fertile even when they are 3 years or more of age. Male no. 2 was twice placed with virgin females, first at the age of 3 years, 64 days, and

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again at 3 years, 76 days; while male no. 7 was mated with a virgin female when the former was exactly 3 years of age. In all these cases normal offspring were produced. Females, however, have never laid fertile eggs when more than 1 year and 94 days old.

RESISTANCE TO STARVATION

The length of time flour beetles can live with no food whatever is greatly influenced by the temperature, resistance to starvation increasing inversely with the temperature. Also a relative humidity of about 60 percent is more favorable for survival than one of 30 percent or less. Several experiments on starvation were made by placing adults or larvae of known age in individual vials with no food and keeping them at the desired temperature and humidity. These were examined daily until the last individual had died.

Adults of the two species seemed equally resistant to starvation. At 30° C. adults will survive for about 2 weeks, the longest period any of 25 individuals of both species survived being 18 days. At ordinary room temperatures during the winter the longest period recorded was 23 days; at 15° some survived for 27 days, at 10° several individuals lived over 40 days, and one adult, *T. confusum*, for 51 days. Larvae seem to be slightly more resistant to starvation than adults. At 30° the longest period recorded for a larva was 23 days. At ordinary room conditions in winter one individual survived 46 days, and at 15° the last larva was not dead until the fifty-fourth day.

Larvae without food will molt and change to pupae and adults nearly as readily as those with food. Those individuals that changed to adults during the experiments lived as long as, and sometimes longer than, those that remained in the larval stage.

MATING

Among pairs kept under observation mating occurred rather frequently. It usually began within a day or two after emergence and probably continued at frequent intervals throughout life. Frequent mating is not necessary for the production of fertile eggs. In certain instances females have been known to continue laying viable eggs for a period of 5 months after being segregated from males.

OVIPOSITION

The study of oviposition in *Tribolium* seems to have received very little attention. However, when it is considered that the oviposition period may last more than a year and that it is almost impossible to locate the eggs in the flour, it is not surprising that more work has not been done along this line. In the experiments made by the writer 25 pairs of each species were segregated on emergence and placed in different foods and under different conditions of temperature and humidity. Small vials, lightly stoppered with cotton, were used as containers. A pair of adults was placed in each vial and changed to another vial every day. Various methods of locating the eggs were tried, but it was found that the method, first advocated by Chapman (*17*), of counting the larvae rather than the eggs was

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more accurate. It was found by an actual count of both the eggs and the resulting larvae, that approximately 90 percent of the eggs of young females were viable. As the females increased in age the percentage of viable eggs gradually decreased. Thus the actual number of eggs laid is at least one-ninth greater than indicated by the figures given in tables 10 and 11, which represent only the eggs that hatched.

PREOVIPOSITION PERIOD

The length of the preoviposition period may range from 4 to an indefinite number of days, depending on the temperature. Mated females of either species placed in the incubator at 27° C. usually began to lay viable eggs within 1 week after emergence. Adults emerging late in the spring or in the summer likewise began to oviposit within a few days. Those adults which emerged during the winter, however, and were kept at room conditions usually did not begin ovipositing until the approach of warm weather late in March or in April.

DURATION OF OVIPOSITION PERIOD

The flour beetles have a very long oviposition period. The average period for a number of females of *T. castaneum* in laboratory tests was 148 days at 27° C. and 174 days at ordinary room temperatures. For *T. confusum* the average oviposition period at 27° was 235 days and at room conditions 277 days. The longest oviposition periods recorded are 308 days for *T. castaneum* and 432 days for *T. confusum*. Both of these individuals were kept under ordinary room conditions.

RATE OF OVIPOSITION

In no case were more than 13 viable eggs laid in 1 day by a single female, and the average was only 2 or 3 per day. Under optimum conditions Brindley (*12*) records 18 viable eggs in 1 day and a much higher daily average than indicated by the author's records.

NUMBER OF EGGS LAID

The total number of eggs laid seems to depend mainly upon the food. Under the various conditions of temperature and food of the oviposition tests the average number of viable eggs laid by individual females of *T. castaneum* was 327 and of *T. confusum* 458. The greatest number of viable eggs laid by *T. castaneum* was 956, while 976 was the greatest number laid by *T. confusum*.

Tables 10 and 11 give data on the oviposition and longevity of the two species.

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TABLE 10.—*Data concerning oviposition and longevity of Tribolium castaneum*

Pair no.	Date male emerged	Date female emerged	Date mated	Date first viable egg laid	Length of preoviposition period	Date last viable egg laid	Length of oviposition period	Total viable eggs laid	Average viable eggs laid per day	Date male died	Date female died	Length of postoviposition period [1]	Longevity of male	Longevity of female	Temperature	Food
	1930	1930	1930	1930	*Days*	1930	*Days*	*Number*	*Number*			*Days*	*Days*	*Days*	° *C.*	
1	[2]	[2]	Jan. 27	Feb. 5	------	June 4	119	149	1.25	Nov. 14, 1930	June 12, 1930	8	------	------	27	Bran.
2	Feb. 8	Feb. 8	Feb. 13	Feb. 17	9	Aug. 23	187	283	1.51	Feb. 12, 1931	Sept. 6, 1930	14	369	210	27	Do.
3	do	do	do	Feb. 15	7	July 1	136	273	2.01	Feb. 6, 1931	July 2, 1930	1	363	144	27	Do.
4	Feb. 9	do	do	Feb. 18	10	Sept. 9	203	643	3.17	Nov. 3, 1931	Sept. 23, 1930	14	632	227	27	Whole-wheat flour.
5	do	Feb. 9	do	Feb. 17	8	Oct. 7	232	572	2.47	Mar. 12, 1931	Oct. 8, 1930	1	396	241	27	Do.
6	Feb. 8	Feb. 8	do	Feb. 14	6	July 30	166	593	3.57	Dec. 20, 1931	July 30, 1930	0	680	172	27	Do.
7	Feb. 9	Feb. 9	do	Feb. 21	12	July 11	140	438	3.13	June 23, 1931	July 21, 1930	10	499	162	27	Do.
8	do	do	do	Feb. 17	8	June 28	131	178	1.36	July 12, 1932	July 11, 1930	13	884	152	27	Do.
9	do	do	do	Feb. 20	11	July 21	151	206	1.36	Apr. 26, 1932	July 22, 1930	1	807	163	27	Do.
10	do	do	do	Feb. 18	9	July 17	149	477	3.20	Feb. 16, 1931	July 30, 1930	13	372	171	27	Middlings.
11	do	do	do	Feb. 15	6	May 2	76	153	2.01	Sept. 15, 1930	May 7, 1930	5	218	87	27	Do.
12	Feb. 10	do	do	Feb. 13	4	May 6	82	161	1.96	Jan. 3, 1932	May 14, 1930	8	692	94	27	Do.
13	Feb. 11	Feb. 10	do	Apr. 7	56	Sept. 18	164	323	1.97	Aug. 23, 1930 [3]	Sept. 24, 1930	6	------	226	[4]	Do.
14	do	do	do	Mar. 28	46	July 27	121	281	2.32	June 26, 1930	Aug. 9, 1930	13	135	180	[4]	Do.
15	Feb. 13	Feb. 12	Feb. 20	Mar. 16	32	Sept. 26	194	608	3.13	July 21, 1932	Oct. 2, 1930	6	889	232	[4]	Whole-wheat flour.
16	Feb. 15	Feb. 13	do	Mar. 25	40	Aug. 28	156	528	3.38	Oct. 26, 1931	Sept. 3, 1930	6	618	202	[4]	Do.
17	Feb. 12	Feb. 12	do	Mar. 21	37	July 30	131	408	3.11	May 8, 1932	Aug. 1, 1930	2	816	170	[4]	Do.
18	do	Feb. 11	Feb. 13	Apr. 16	64	June 12	57	21	.37	Feb. 20, 1931	June 16, 1930 [3]	------	373	------	[4]	White flour.
19	do	Feb. 12	Feb. 20	May 12	89	Aug. 9	89	17	.19	Mar. 16, 1931	Jan. 12, 1931	156	397	334	[4]	Do.
20	do	do	do	Apr. 16	63	Feb. 18 [5]	308	163	.53	[3] 1930	July 15, 1931	147	------	518	[4]	Oatmeal.
21	do	do	do	Apr. 3	50	Dec. 19	260	131	.50	Dec. 16, 1931	Mar. 16, 1931	87	672	397	[4]	Do.
22	do	do	do	Mar. 24	40	Sept. 8	168	74	.44	Dec. 27, 1931	Oct. 25, 1930 [3]	------	683	------	[4]	Do.
23	Feb. 14	Feb. 14	do	Mar. 28	42	Jan. 8 [5]	286	956	3.34	Mar. 3, 1931	Jan. 23, 1931	15	382	343	[4]	Corn meal.
24	Feb. 16	Feb. 16	do	Apr. 4	47	Sept. 22	171	412	2.41	Oct. 15, 1931	Jan. 10, 1931	110	606	328	[4]	Do.
25	do	do	do	Mar. 18	30	Aug. 21	156	134	.86	Mar. 9, 1930 [3]	Sept. 19, 1930	29	------	215	[4]	Do.

[1] Only the viable eggs have been counted. Many infertile eggs are laid after the last viable egg, but these are not considered in this table.
[2] Taken in copulation.
[3] Escaped.
[4] Room temperature.
[5] 1931.

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TABLE 11.—*Data concerning oviposition and longevity of Tribolium confusum*

Pair no.	Date male emerged	Date female emerged	Date mated	Date first viable egg laid	Length of preoviposition period	Date last viable egg laid	Length of oviposition period	Total viable eggs laid	Average viable eggs laid per day	Date male died	Date female died	Length of postoviposition period [1]	Longevity of male	Longevity of female	Temperature	Food
					Days		*Days*	*No.*	*No.*			*Days*	*Days*	*Days*	°*C.*	
1	Dec. 3, 1929	Dec. 8, 1929	Dec. 9, 1929	Dec. 20, 1929	12	Oct. 10, 1930	294	169	0.57	July 8, 1931	Nov. 10, 1930	31	582	337	27	White flour.
2	Dec. 14, 1929	Dec. —, 1929	Dec. 16, 1929	Dec. 21, 1929	-----	Dec. 2, 1930	346	161	.47	Aug. 4, 1931	Apr. 20, 1931	139	598	-----	27	Do.
3	[2]	[2]	----do----	----do----	-----	Nov. 20, 1930	334	230	.69	Nov. 8, 1930	Feb. 16, 1931	88	-----	-----	27	Do.
4	[2]	[2]	----do----	Dec. 23, 1929	-----	June 26, 1930	185	158	.85	Aug. 4, 1931	July 7, 1930	11	-----	-----	27	Oatmeal.
5	Dec. 18, 1929	Dec. 18, 1929	Dec. 19, 1929	----do----	5	Mar. 21, 1930	88	125	1.42	Jan. 8, 1930	July 16, 1931	482	21	575	27	Do.
6	Dec. 28, 1929	Jan. 2, 1930	Jan. 4, 1930	Jan. 23, 1930	21	May 1, 1930	98	270	2.76	Feb. 10, 1931	May 7, 1930	6	409	125	27	Middlings.
7	[2]	[2]	Dec. 16, 1929	Dec. 21, 1929	-----	Aug. 2, 1930	224	209	.93	Sept. 18, 1930	Sept. 16, 1930	45	-----	-----	27	Bran.
8	Dec. 16, 1929	Dec. 26, 1929	Dec. 27, 1929	Jan. 6, 1930	11	Aug. 10, 1930	216	331	1.53	Mar. 17, 1931	Aug. 19, 1930	9	456	236	27	Do.
9	Jan. 27, 1930	Jan. 27, 1930	Jan. 29, 1930	Feb. 3, 1930	7	Oct. 8, 1930	247	412	1.66	Jan. 9, 1931	Jan. 20, 1931	104	347	358	27	Do.
10	----do----	----do----	----do----	----do----	7	Nov. 12, 1930	282	424	1.50	Jan. 8, 1931	Jan. 5, 1931	54	346	343	27	Do.
11	----do----	----do----	----do----	Feb. 1, 1930	5	Dec. 27, 1930	329	342	1.04	May 2, 1931	Jan. 6, 1931	10	460	344	27	Do.
12	----do----	----do----	----do----	----do----	5	Nov. 17, 1930	289	282	.97	Apr. 28, 1931	Jan. 9, 1931	53	456	347	27	Do.
13	----do----	----do----	----do----	Jan. 31, 1930	4	July 31, 1930	181	328	1.81	Aug. 3, 1932	Dec. 16, 1931	503	919	688	27	Whole-wheat flour.
14	----do----	----do----	----do----	Feb. 2, 1930	6	Nov. 18, 1930	289	905	3.13	Apr. 5, 1932	Dec. 1, 1930	13	799	308	27	Do.
15	----do----	----do----	----do----	Feb. 6, 1930	10	Oct. 9, 1930	245	330	1.35	May 2, 1932	Oct. 3, 1931	359	826	614	27	Do.
16	Feb. 8, 1930	Feb. 7, 1930	Feb. 13, 1930	Feb. 17, 1930	10	July 28, 1930	161	389	2.42	Feb. 25, 1930 [3]	Jan. 2, 1932	523	-----	694	27	Do.
17	Feb. 7, 1930	Feb. 8, 1930	----do----	Feb. 18, 1930	10	Oct. 26, 1930	250	677	2.71	Jan. 30, 1932	Oct. 30, 1930	4	722	264	27	Do.
18	Feb. 12, 1930	Feb. 10, 1930	----do----	----do----	8	Aug. 17, 1930	180	491	2.73	Nov. 14, 1931	Aug. 20, 1930	3	640	191	27	Do.
19	Jan. 27, 1930	Feb. 4, 1930	Feb. 6, 1930	Apr. 25, 1930	80	----do----	114	521	4.57	July 29, 1930 [3]	Aug. 26, 1930	9	-----	203	[4]	Do.
20	----do----	Jan. 30, 1930	Feb. 3, 1930	Apr. 27, 1930	87	Sept. 19, 1930	145	596	4.11	Oct. 27, 1930 [3]	Sept. 25, 1930	6	-----	238	[4]	Do.
21	----do----	Jan. 27, 1930	Jan. 29, 1930	Feb. 4, 1930	8	Apr. 12, 1931	432	882	2.04	Dec. 19, 1932	Feb. 22, 1932	316	1,057	756	[4]	Do.
22	Jan. 29, 1930	Jan. 29, 1930	----do----	Apr. 6, 1930	67	Feb. 17, 1931	317	563	1.78	Oct. 4, 1930	Aug. 28, 1932	558	248	942	[4]	Do.
23	Jan. 27, 1930	Jan. 30, 1930	Feb. 3, 1930	Mar. 19, 1930	48	May 12, 1931	419	945	2.25	July 14, 1932	Sept. 3, 1932	480	899	947	[4]	Do.
24	----do----	Jan. 31, 1930	----do----	Mar. 22, 1930	50	Dec. 5, 1930	258	729	2.83	June 28, 1932	July 20, 1931	227	883	535	[4]	Do.
25	Jan. 30, 1930	Feb. 4, 1930	Feb. 6, 1930	Mar. 17, 1930	41	Nov. 24, 1930	252	976	3.87	Nov. 5, 1933	Jan. 8, 1931	45	1,375	338	[4]	Do.

[1] Only the viable eggs have been counted. Many infertile eggs are laid after the last viable egg, but they are not considered in this table.
[2] Taken in copulation.
[3] Escaped.
[4] Room temperature.

INTERRELATION WITH OTHER ANIMALS

MEDICAL IMPORTANCE

Flour beetles have never been considered of medical importance, although it is known that many live larvae, and other stages as well, are accidentally swallowed in the eating of uncooked breakfast foods, dried fruits, nuts, or chocolate.

In an article treating of infestation of human beings by the cestode *Hymenolepis diminuta* Rud., in Japan, Momma (*69*) lists *Tribolium ferrugineum* in a series of insects which have been determined by Hongo to be intermediate hosts of this tapeworm in that country. He also states his belief that infestation of humans is due to the accidental swallowing of an infested individual of any of that series of intermediate hosts.

ENEMIES OF TRIBOLIUM BEETLES

PROTOZOAN DISEASES

One disease, caused by a coccidian of the genus *Adelina* (Park (*75*)), is of rather common occurrence among species of *Tribolium*. This disease was first reported by Riley (*85*) in 1921 in Minnesota and mentioned in 1922 by Riley and Krogh (*86*), both of these references being merely records of the observance of the disease.

The parasite invades the fat cell of the host. The larvae, pupae, and adults are affected, and within a few months the disease may practically exterminate an entire culture of beetles. During the present investigations the author often noticed that numbers of larvae and beetles would die from some disease. Specimens were given for examination to G. F. White, who reported them to have died from this protozoan infection. To date the disease has been reported only in *Tribolium confusum* and *T. castaneum*.

Another protozoan disease of these flour beetles was described briefly by White in 1923 (*103*). The causal protozoan is a neosporidian which invades the fat body of the larva, and may also be found in the pupa and adult beetle. Late in the course of the disease the sick larvae may be less active, slightly distended, and more opaque. After a few months most of the diseased insects have died.

It is not known whether these diseases can be used in the artificial control of these flour beetles.

MITES AFFECTING TRIBOLIUM

The most common parasite of the flour beetles is the mite *Acarophenax tribolii* Newstead and Duvall (fig. 20). This tarsonemid was described from *Tribolium confusum* and *T. castaneum* in wheat from Australia (*72*), but the beetles may have become infested in England. Newstead and Duvall also reported the mite from *Tribolium* in "Plate maize." These mites were first noticed in North America by the author in 1930 and were identified by H. E. Ewing. Specimens were recorded from the District of Columbia, Virginia, Mississippi, and Texas, and specimens, tentatively identified by the author as the above species of mite, were found on *Tribolium* adults

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in Kansas and Oklahoma. Holdaway (*52*) also reported this mite from *T. confusum* in Minnesota. The author has found these mites also on *Gnathocerus cornutus* Fab., *Palorus ratzeburgii* Wissm., and *Latheticus oryzae* Waterh. A description and full account of their life history is given by Newstead and Duvall (*72*). These mites cling to the body of their host and draw their nourishment from it, and it seems that they do little more than irritate the adult beetles. Adults seem to be more heavily infested, but all stages may be attacked. Many eggs are destroyed by the gravid female mites that attack the beetle's eggs a few days before the young mites are ready to come forth. Then the mother dies, and the young mites emerge, leaving her body an empty shell.

Another mite, the common *Pediculoides ventricosus* Newport, sometimes infests the immature stages of *Tribolium*, killing all individuals that it attacks. *Pediculoides* was observed in the laboratory in rearings of *Tribolium castaneum* and *T. confusum* in 1930, but it appeared that these beetles were not preferred hosts and were not bothered when sufficient lepidopterous larvae were present.

FIGURE 20. — A flour beetle (*Tribolium castaneum*) with several mites (*Acarophenax tribolii*) attached to the ventral surface, × 20.

HYMENOPTEROUS PARASITES

Two hymenopterous parasites, both in the family Bethylidae, have been bred from *Tribolium*. Only one of these, *Rhabdepyris zeae* Turner and Waterston (fig. 21), has been recorded in nature as a parasite of the flour beetles. Gahan (*44*) gives records of *Rhabdepyris* as a parasite of *Tribolium* in Indiana, Louisiana, and possibly from *Tribolium* in a shipment of grain from West Africa to England. Specimens in the United States National Museum from Texas and Florida also belong to this species.

The other bethylid, *Sclerodermus immigrans* Bridwell, was experimentally bred from *Tribolium* in Hawaii by Bridwell (*11*) in 1920 but has not been recorded as attacking it in nature.

PREDATORS

COLEOPTERA

The cadelle, *Tenebroides mauritanicus* L., has been reported as attacking flour beetles by Johnson (*57*, *no. 4*), Washburn (*99*), and Durrant and Beveridge (*40*). These observations concern mainly the adult cadelle attacking flour beetle larvae. The experiments of Back and Cotton (*6*) show that cadelle larvae are not normally predacious and will attack other insects very infrequently and then usually do not feed on the carcass of their victim. In recent experiments in the laboratory, cadelle larvae showed no tendency to attack larvae, pupae, or adults of *Tribolium*.

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"A species of *Rhizophagus*" has been reported as preying on *Tribolium castaneum* by Muller (*41*) in peanuts arriving in London from Sierra Leone.

HEMIPTERA

Several species of predacious Hemiptera frequent flour mills, but none has been definitely associated with *Tribolium* except by Roubaud (*87*). In April 1933 numbers of a small anthocorid were observed by the author in a breeding jar containing no other possible host but *T. confusum* feeding in cracked grain and flour that had

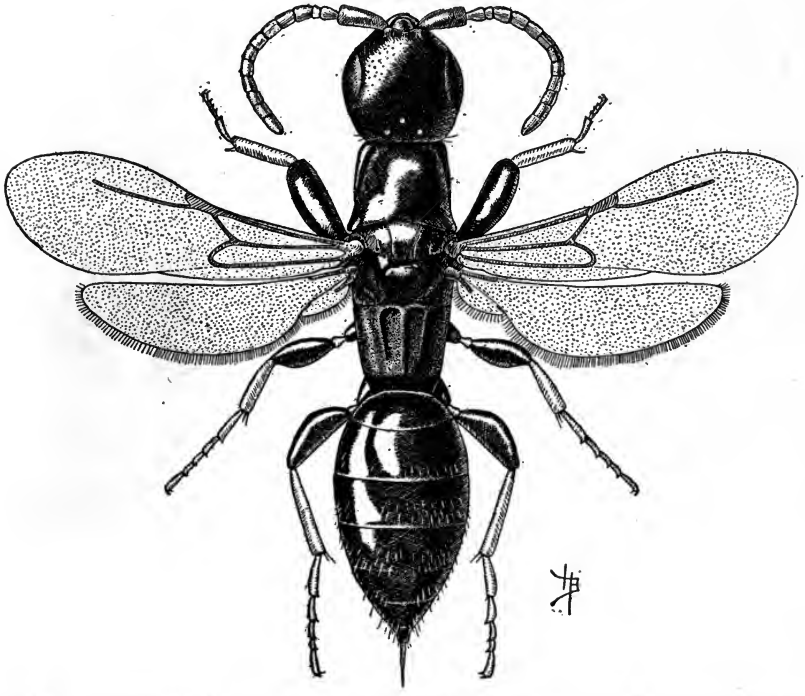

FIGURE 21.—*Rhabdepyris zeae*, a hymenopterous parasite of the flour beetles: Adult female, × 27.

been collected in a flour mill in Washington, D. C., in December 1932 and had not been molested since that date. Specimens were identified by H. G. Barber as *Xylocoris cursitans* Fallen, which is generally predacious on small, soft-bodied insects and in this case was undoubtedly attacking the small larvae.

MISCELLANEOUS ENEMIES

Mice (*Mus musculus*) may also be considered as enemies of *Tribolium*, as they sometimes eat these beetles, as well as many other kinds of insects.

TRIBOLIUM AS A PREDATOR

There are several records, more or less definite, of *Tribolium* beetles preying on larvae of the Mediterranean flour moth and other insects.

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A note by Johnson (*56*) is interesting, although more humorous than practical. He says:

> A miller in California called my attention to the fact that he had seen this beetle feeding on the larvæ of the Mediterranean flour moth (*Ephestia kühniella*) and even contemplated the erection of a plant where he could breed the beetle, so he could turn them loose on the terrible flour moth, which everywhere filled his mill.

Washburn (*99, pp. 36–37, 44*) states:

> *Tribolium confusum* * * * has been known to devour the pupæ of the flour moth. The so-called "bolting-cloth beetle" (*Tenebroides mauritanicus*) of California eats larva and pupa of the flour moth and larva and adult of Tribolium. * * * It [*T. confusum*] is said to attack and eat the larvæ of the Mediterranean Flour Moth.

Alden and Farlinger (*1, p. 482*) state:

> The rust red flour beetle [*Tribolium ferrugineum* Fab.] also fed on Sitotroga [*cerealella*] eggs and the dead bodies of the adults.

The author has never observed *Tribolium* actually attacking any other living insects and does not believe that it does so normally, except perhaps in the case of eggs and very young larvae. However, it has been frequently observed that in cases where *Tribolium* and other species of insects are present in the same breeding jar the *Tribolium* will soon crowd out the other insects. Whether this is due to the killing of the other insects or to mechanical crowding is a matter of conjecture. It is probably due mainly to the breaking of the eggs and the killing of the young larvae by the adult flour beetles as they run around over the flour and, to a lesser extent, to the actual devouring of eggs and young larvae by these flour beetles. This same reduction in the number of eggs is found in unmixed lots of *Tribolium* and is undoubtedly caused by the mechanical breaking of the eggs by the movements of the adults.

Kotinsky (*60*) records *Tribolium castaneum* as an enemy of the harmful leaf-cutting bee *Megachile palmarum* Perkins in Honolulu. He was not certain whether the *Tribolium* actually preyed on the bee larva or merely fed on the pollen in the cells, but in either case the bee larva died.

In India, *T. castaneum* has been noted associated with the lac insects (*Tachardia*) by Mahdihassan (*68, p. 69*) and by Imms and Chatterjee (*54*) who state:

> We have also dissected this insect from among the chambers of the lac where its larval stage is spent. * * * It is probable that it feeds only on the lac and not on the Tachardiae, but it is to be regarded as one of the more important Coleopterous enemies of lac.

CONTROL MEASURES

CONTROL IN FLOUR MILLS

Flour mills are open to infestation from three main sources, (1) the grain stream, (2) returned infested flour, and (3) used bags and second-hand machinery. As has already been stated, *Tribolium* beetles cannot live in perfectly sound grain, but nearly all lots of grain are damaged to a certain extent, either through rough handling

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or because of the work of the true grain weevils, and so any *Tribolium* present can live until they reach and infest the flour mill.

After a flour mill is once infested with these beetles, two satisfactory methods of control are by fumigation or superheating. Other methods, such as cleaning out the machinery regularly, local fumigating, and spraying can be used in conjunction with the above methods. So far biological control has not proved practical.

Perhaps the most satisfactory, and certainly the most widely used, fumigant for flour beetles is hydrocyanic acid gas (*4*, *7*, *32*). Although this gas is deadly to human life it can be handled with comparative safety by well-trained fumigators. Chloropicrin (*34*, *96*) is also used as a mill fumigant, and when properly applied is quite effective. Owing to its lachrymatory effect it has not become so popular a mill fumigant as hydrocyanic acid gas.

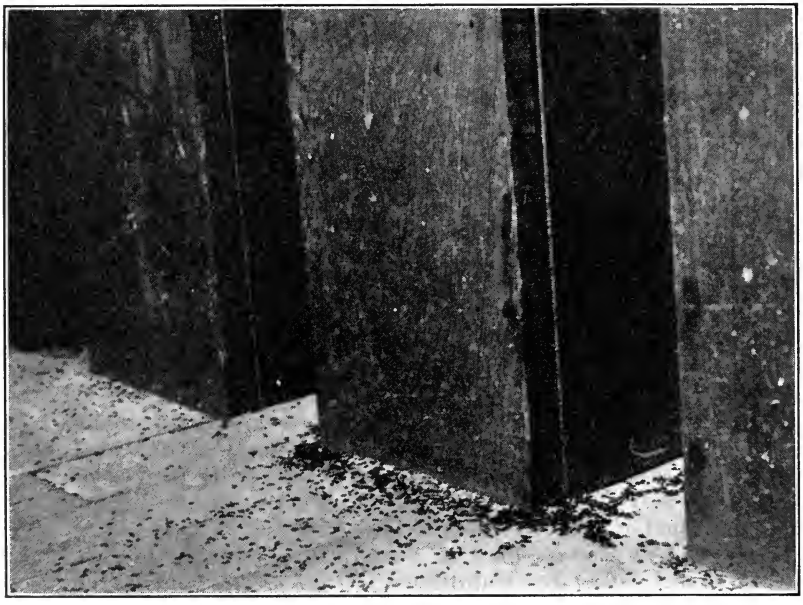

FIGURE 22.—Bases of elevator legs after application of the heat method of control. Large numbers of beetles have crawled out of the cracks and died on the floor. (Back.)

Control by heat (*4*, *18*, *32*, *33*, *34*, *48*) is practiced to a certain extent (fig. 22), and this method has the advantage of being harmless to the operator.

Prepared flours and cereals put up in package form are frequently infested by flour beetles. Such products should be sterilized by heat derived from steam, hot air, or electricity, and should pass directly from the sterilizer to the packer where the cartons are packed and sealed. This process, if properly carried out will insure a product free from insects. Electrical machines are now on the market for sterilizing small packages of prepared cereals by disruptive discharge (*45*). This method shows considerable promise.

CONTROL OF FLOUR BEETLES IN HOUSES

The method used for the control of these insects in flour and cereals in dwellings are necessarily quite different from those advocated for use in mills and warehouses.

These pests, in practically all cases, are originally brought into the house through infested flour or breakfast cereals, and when such material is allowed to stand for some time the infestation may spread to nearly every article of food in the house. Whenever there is any reason to suspect the presence of beetles, larvae, or eggs, the safest and simplest procedure is to place the product in a shallow pan and heat it in an oven for a time with a very low fire. This treatment will kill all stages of the insects without injuring the flour or cereal, and is especially useful in the frequent cases where, although no beetles or larvae are to be found, eggs may have been deposited in the food, which later would develop into larvae and beetles. The exposures shown in table 12 will kill all stages of these insects.

TABLE 12.—*Temperatures and time of exposure necessary to kill all stages of the flour beetles in flour, meal, or cereals*

Temperature (°C.)	Exposed individuals	In 1 inch of flour	In 3 inches of flour
50	1½ hours	4 hours	8 hours.
60	15 minutes	45 minutes	4 hours.
70	10 minutes	40 minutes	2½ hours.
80	8 minutes	30 minutes	2 hours.

Temperatures below 79° C. are not likely to injure flour or cereal, but 80° and above may scorch flour, and so should be avoided. Breakfast cereals may, however, be heated to about 90° without being injured. Further data on oven heating to kill flour beetles is given by Chapman (*17*).

When these beetles have already become established in a pantry or flour bin the best procedure is to destroy all foodstuffs known to be infested, sterilize by the foregoing method all those that may be infested, and give the entire kitchen and pantry a thorough cleaning, including scalding of all cracks with boiling water.

In cases where it is impossible to rid a place of insects without fumigation, the directions given in the articles referred to should be studied and carefully followed.

SUMMARY

The confused flour beetle, *Tribolium confusum* J. du V., and the rust-red flour beetle, *T. castaneum* (Hbst.), are by far the most abundant and destructive beetles infesting flours and other prepared cereal products. These insects are cosmopolitan and are now recorded as pests in practically every civilized country of the world.

A partial revision of the genus *Tribolium* is given, in which the name *castaneum* Herbst is shown to be the correct name for the species commonly known as *ferrugineum* Fab. Seven species are in-

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cluded in the genus. These are *castaneum*, *confusum*, *madens*, *destructor*, *gebieni*, *indicum*, and *myrmecophilum*.

These beetles, excepting *myrmecophilum* and *gebieni*, are probably native to the region comprising southwestern Asia and the eastern Mediterranean lands. Their original habitat was under the bark of trees and in rotting logs, where they probably lived as scavengers.

Both *T. confusum* and *T. castaneum* are cosmopolitan, but *T. confusum* is more common in temperate regions, and *T. castaneum* is more of a subtropical insect. *T. madens* has been recorded from North America, Europe, and Egypt, and *T. destructor* from Germany and the Netherlands. *T. indicum*, *T. gebieni*, and *T. myrmecophilum* apparently have a very limited range, the first being recorded from India and northern Africa, the second only from Paraguay, while the last is known only from southeastern Australia. Most of the many references to these beetles in literature are records of the damage done by them.

The flour beetles are particularly injurious in flour mills and in other establishments that prepare cereal products. They are nearly omnivorous and have been reported breeding in and damaging flour and all other prepared cereal products, grain and seed, animal matter and especially dry insects specimens, yeast, nuts, dried fruits, chocolate, certain spices, and other miscellaneous plant products.

The eggs, which are laid directly in the flour or other food material, are covered with a sticky substance that causes the foodstuffs to adhere to them and often completely cover them.

The incubation period for *T. castaneum* averaged 4 days at 30° C., 5.2 days at 27°, 6 days at 25°, and about 8.8 days at room conditions where the temperature averaged 22°. The incubation period for *T. confusum* averaged 6.8 days at 27°, and 12.8 days at room conditions where the temperature averaged 21°.

The number of larval instars ranges from 5 to 11 or more, the usual number being 7 or 8. Environmental conditions, especially food and temperature, influence the number of instars considerably. However, there may be considerable individual variation in the number of instars of larvae reared under identical conditions.

The duration of the larval period ranges from 22 to over 100 days according to the influence of environment and the effect of individual variation. The optimum temperature for development seems to be close to 30° C. for both species. Of the foods used, whole-wheat flour was most favorable for development, followed by middlings, bran, corn meal, and white flour in the order named. Measurements for the various stages and for the larval instars, including the width of the head capsule, are given.

The average pupal periods were, for *T. castaneum* at 30° C., 5 days, at 27°, 7.1 days, at 25°, 8.8 days, at room temperature in early summer, 8.5 days; and for *T. confusum* at 27°, 7.9 days in continuous light and 8.7 days in continuous darkness. Adult males and females are so nearly alike in external appearance that they are difficult to separate, although the sexes can be readily recognized in the pupal stage by the characteristic shape of the venter of the last abdominal segment.

Adults of *T. castaneum* can fly short distances, but adults of *T. confusum*, although provided with wings, have never been observed

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to fly. Adults of both species possess scent glands that give off a pungent odor.

Breeding continues the year round in heated buildings, but in unheated mills in the Northern and Central States only adults are present during the winter.

Adults have been known to live as long as 3 years and 271 days. The average longevity of the adults used in the oviposition experiments was as follows: *T. confusum* males, 634 days, females, 447 days; *T. castaneum* males, 547 days, females, 226 days. *T. confusum* males have proved fertile at 3 years, 76 days of age. The greatest age at which a female laid fertile eggs was 1 year and 94 days.

Resistance to starvation varies inversely with the temperature, and the two species seem equally resistant. The longest survival periods for adults without food are as follows: At 30° C., 18 days, at room temperature, 23 days, at 15°, 27 days, at 10°, 51 days. The longest survival periods for larvae without food were 23 days at 30°, 46 days at ordinary room conditions, and 54 days at 15°.

The longest oviposition periods recorded were 432 days for *T. confusum* and 308 days for *T. castaneum*. The average oviposition period for *T. confusum* was about 8 months, while that of *T. castaneum* was about 5½ months. The average number of eggs laid per day during the entire oviposition period of any female was 2 or 3, and the highest number recorded in 1 day was 13. The greatest number of viable eggs laid by a single female during its entire oviposition period was 976 for *T. confusum* and 956 for *T. castaneum*. The average number laid by *T. confusum* females was 458 while that of *T. castaneum* was 327.

T. castaneum has been experimentally proved to be one of the intermediate hosts of the tapeworm *Hymenolepis diminuta* in Japan.

A disease caused by a coccidian, *Adelina* sp., is often found in the rearings of *Tribolium* and kills large numbers of the insects. The mite *Acarophenax tribolii* is the most common parasite of these beetles. Another mite, the common *Pediculoides ventricosus*, sometimes attacks *Tribolium*. The hymenopterous parasites *Rhabdepyris zeae* and *Sclerodermus immigrans* have been recorded from *Tribolium* but seem to be rather rare. Predators attacking *Tribolium* are the hemipteron *Xylocoris cursitans* and adults of the cadelle, *Tenebroides mauritanicus*. Adults of *Tribolium* may themselves be predatory to a certain extent.

Control methods include fumigation with hydrocyanic acid gas or chloropicrin, and the use of heat.

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UTILIZATION AND COST OF POWER ON MISSISSIPPI AND ARKANSAS DELTA PLANTATIONS

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UNITED STATES DEPARTMENT OF AGRICULTURE, WASHINGTON, D. C.
IN COOPERATION WITH THE AGRICULTURAL EXPERIMENT STATIONS OF MISSISSIPPI AND ARKANSAS

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WASHINGTON, D. C.

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In Cooperation with the Agricultural Experiment Stations of Mississippi and Arkansas

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INTRODUCTION

An outstanding development in American agriculture in the last century has been the rapid rate at which animal and mechanical power have been substituted for man labor in the production of farm crops. The movement has made greater progress in the production of the grain and hay crops than it has throughout the Cotton Belt in the growing and harvesting of cotton; but, where climatic, topographic, soil, and labor conditions are not unfavorable, many cotton planters

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have matched accomplishments of farmers in the Corn Belt and other regions in the adoption of power methods of farming. The use of power in large units in cotton production has made most headway in the relatively new cotton areas in Texas and Oklahoma and in the Mississippi River Delta where conditions are more generally favorable than in the old Cotton Belt to machine methods of production.

When perfection of mechanical cotton pickers, which for a number of years have been aggressively experimented with, reaches the stage that will make possible the displacement of labor in the harvesting operation, a momentous handicap to a wider use of power and large-scale machinery in cotton production will have been removed. Throughout large sections of the old Cotton Belt the nature of the land is such, and its ownership is sufficiently consolidated, that a high degree of mechanization is feasible if it were no longer necessary to have an abundant supply of labor for the very intensive operation of hand picking.

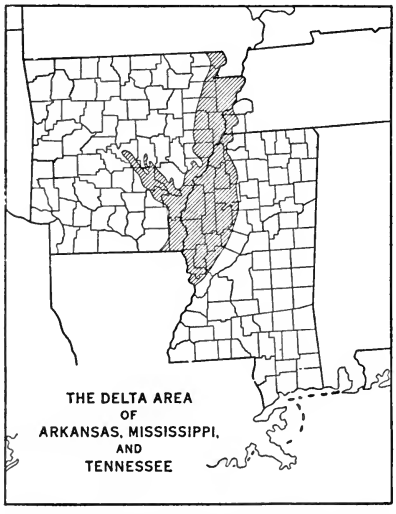

FIGURE 1.—Thousands of square miles of land here comprise one of the richest and most important agricultural areas in the world.

PURPOSE AND SCOPE OF THE STUDY

Much first-hand experience in the use of power and machinery on a large scale has been gained by the planters in the Mississippi River Delta. A knowledge of that experience should be helpful to other planters whose situations are favorable to mechanized cotton growing but who have not readjusted their production methods. With that thought in mind, the United States Department of Agriculture, in cooperation with the agricultural experiment stations in Mississippi and Arkansas, made a study of the use and cost of power on 161 plantations in the Delta sections of those two States. A representative of one of the cooperating institutions visited each planter during the spring of 1930 and the following data were obtained: (1) The kinds and number of power units used in connection with the operation of the plantation in 1929; (2) the operations performed and the amount of work done during the year with each type of power; (3) the cost in 1929 of using each type of power; and (4) such other items as show the relative advantages of the different kinds of power in operating the plantation. The planters interviewed were located along the Mississippi, Yazoo, and Arkansas Rivers in 10 counties in Mississippi and 9 counties in Arkansas (fig. 1). One or more tractors were owned on each of 98 plantations; the other 63 plantations used only mules or other work stock for power.

PLANTATION ORGANIZATION

The plantations surveyed were classified according to the type of power used: (1) "Mule plantations", or plantations on which mules were the only kind of power owned for drawbar work; (2) "general-

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purpose tractor plantations", or plantations on which mules and one or more general-purpose or row-crop-cultivating tractors were owned; (3) "ordinary-tractor plantations", on which mules and one or more 2- or 3-plow tractors of the conventional type were owned; and (4) "ordinary and general-purpose tractor plantations", hereinafter referred to as "mixed-tractor plantations", on which both ordinary and general-purpose tractors were owned in addition to mules. Plantations of the first two power types were further classified according to size as measured by number of acres in cotton. The numbers of records in the two latter power-type groups were too few for analysis if the plantations in those groups were further classified according to size.

The average acreage of each of the different crops commonly grown on the plantations in each of the different power type and size groups are shown in table 1. Considering all plantations, 75 percent of the crop land was in cotton, 14 percent in corn, and 11 percent in other crops, chiefly cowpeas, soybeans, and alfalfa. The average proportion of the crop land in cotton was largest, 77 percent, on the mule plantations and smallest, 70 percent, on the mixed-tractor plantations. Corn occupied a larger average proportion, 16 percent, of the crop acreage on the mixed-tractor plantations than on any other group; the smallest proportion, 12 percent, was on the general-purpose tractor group.

TABLE 1.—*Utilization of land on plantations classified by power type and by size, 1929* [1]

Size group (cotton acres)	Plantations surveyed	Size of plantation	Cotton	Corn	Cowpeas and soybeans	Alfalfa	Grain sorghum	Miscellaneous crops	Rotation pasture	Idle and fallow land	Total crop land	Other land
	Number	*Acres*	*Acres*	*Acres*	*Acres*	*Acres*	*Acres*	*Acres*	*Acres*	*Acres*	*Acres*	*Acres*
GENERAL-PURPOSE TRACTOR PLANTATIONS												
150 to 399	19	552	265	50	12	7	2	12	------	17	365	187
400 to 799	27	925	543	112	22	20	9	7	1	35	749	176
800 and over	19	1,950	1,184	157	67	16	24	20	6	29	1,503	447
Total or average	65	1,115	649	107	32	15	12	12	2	28	857	258
MULE PLANTATIONS												
150 to 399	31	460	263	54	5	7	7	6	------	7	349	111
400 to 799	23	1,109	551	92	15	8	8	15	------	13	702	407
800 and over	9	2,165	1,267	286	37	26	21	17	------	------	1,654	511
Total or average	63	941	512	101	14	10	9	11	------	8	665	276
MIXED (ORDINARY AND GENERAL-PURPOSE) TRACTOR PLANTATIONS												
Total or average	19	1,806	933	217	63	62	13	32	------	11	1,331	475
ORDINARY-TRACTOR PLANTATIONS												
Total or average	14	1,361	792	152	20	28	28	33	------	3	1,056	305

[1] For definition of the short expressions used to describe the 4 classes of plantations, see pp. 2 and 3.

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Practically all the work stock on the plantations studied were mules. On the mule plantations there was 1 mule for each 18 acres of crops; on the general-purpose tractor plantations, 1 mule for each 21 acres of crops; and on the ordinary-tractor and mixed-tractor groups, 1 mule for each 20 acres of crops. The number of other work stock, principally saddle horses, averaged 1 horse per plantation, except on the mixed-tractor group, where it averaged 2. Other livestock consisted of milk cows and hogs, kept largely for supplying products for home use, and a few sheep.

POWER UNITS ON PLANTATIONS

Table 2 shows the total number of power units, by kinds, on the plantations studied, classified by power type. The gas engines shown are those of 5 or more horsepower which were doing work that could have been done economically by tractors or mules. Only one plantation used an electric motor for belt operations that required 5 or more horsepower.

TABLE 2.—*Power units on plantations classified by power type and by cotton acreage, 1929*

Size group (cotton acres)	Plantations surveyed	Average cotton acreage	Work mules	Tractors	Motor trucks	Gas engines [1]	Combined harvester-threshers
	Number	*Acres*	*Number*	*Number*	*Number*	*Number*	*Number*
GENERAL-PURPOSE TRACTOR PLANTATIONS							
150 to 399	19	265	286	23	16	3	0
400 to 799	27	543	953	36	12	2	0
800 and over	19	1,184	1,429	38	18	2	2
Total or average	65	649	2,668	97	46	7	2
MULE PLANTATIONS							
150 to 399	31	263	630	0	11	0	0
400 to 799	23	551	843	0	13	2	0
800 and over	9	1,267	860	0	3	0	0
Total or average	63	512	2,333	0	27	2	0
MIXED (ORDINARY AND GENERAL-PURPOSE) TRACTOR PLANTATIONS							
Total or average	19	933	1,259	48	15	5	1
ORDINARY-TRACTOR PLANTATIONS							
Total or average	14	792	751	15	13	1	1

[1] Of 5 horsepower or more, used for work that horses and mules might do.

The number of tractors owned ranged from 1 to 6. Of the 65 general-purpose tractor plantations 44 had 1 tractor, 14 had 2, 5 had 3, 1 had 4, and 1 had 6 tractors. Of the 19 mixed-tractor plantations, which had the largest acreage in cotton and total crop land, 13 had 2 tractors, 3 had 3, 2 had 4, and 1 had 5 tractors. Of the 48

tractors owned on the mixed-tractor plantations, 28 were general-purpose and 20 were ordinary.

On each plantation studied there were work mules. The number ranged from 2 to 198. They were used alone or with other forms of power for the various crop and hauling operations. For all plantations, the number of work mules averaged approximately 43 head. For the individual groups, general-purpose tractor plantations averaged 41 head, mule plantations 37, mixed-tractor plantations 66, and ordinary-tractor plantations 54 head.

Of the 161 plantations surveyed, 87 owned 101 motor trucks. Since 40 percent of the mule plantations, 57 percent of the general-purpose tractor plantations, 72 percent of the ordinary-tractor plantations, and 79 percent of the mixed-tractor plantations had trucks, it is obvious that size of plantation (table 1) was a factor in the ownership of trucks. Furthermore, in view of the increase in numbers, it is evident that the motor truck is considered an important unit of power. According to the 1920 census, there were 2,032 trucks on plantations and farms in Arkansas and Mississippi, and this number by 1930 had increased to 27,503.

UTILIZATION OF POWER ON PLANTATIONS WHERE TRACTORS WERE USED

The use of mechanical power on Delta plantations was of recent development in 1929. Tractors were used for less than 13 percent of the drawbar work on crops on the plantations surveyed. Many planters interviewed were trying out the general-purpose type for the first time. There was, however, a sufficient number of plantations on which cotton was produced largely if not entirely with tractor power to form a basis for study of the economic advantages and disadvantages of tractor power as compared with mule power. On 24 of the 65 general-purpose tractor plantations tractors were the principal type of power used on definite acreages of cotton. Each tractor, with some additional mule labor, was handling an average of about 100 acres of cotton in addition to other crops.

In addition to the tractor, the motor truck offered additional competition for mules. Notwithstanding the mechanical competition, mules on Delta tractor plantations were working over 100 days per head annually.

The average annual hours the different kinds of power were used on the tractor plantations in 1929 are shown in table 3. Power furnished by tractors, motor trucks, mules, and miscellaneous power units is included. The hours shown are the averages for all plantations in the group rather than for only those reporting the particular kind of power.[1] Each average was obtained from the sum of the number of hours the power units in the group were used, without regard to difference in sizes of units.

[1] On Delta plantations about three-fourths of the crop land is planted in cotton and the acreage of cotton defines, perhaps better than any other factor, the size of the business. But it should be remembered that tractors were used to a limited extent on other crops.

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TABLE 3.—*Average annual use of different types of power on tractor plantations classified by type of tractor owned, 1929*

GENERAL-PURPOSE TRACTOR PLANTATIONS

Size group (cotton acres)	Plantations surveyed	Average cotton acreage	Owned power					Hired power
			Tractors		Motor trucks	Mules	Miscellaneous	Mules
			Drawbar work	Belt work				
	Number	*Acres*	*Hours*	*Hours*	*Hours*	*Hours*	*Hours*	*Hours*
150 to 399	19	265	855	29	418	12,944	16	53
400 to 799	27	543	861	52	219	34,510	4	16
800 and over	19	1,184	1,444	116	700	79,100	11	----
Total or average	65	649	1,030	64	418	41,240	10	22

MIXED (ORDINARY AND GENERAL-PURPOSE) TRACTOR PLANTATIONS

Total or average	19	933	1,723	130	640	71,291	63	[1]

ORDINARY-TRACTOR PLANTATIONS

Total or average	14	792	384	86	679	58,000	16	----

[1] 0.3 of an hour of tractor drawbar work was hired.

There was a noticeable difference among groups of plantations in the average number of hours power units were used per year. This was because of differences in size of plantations and in number of individual power units per plantation. Tractors, for example, averaged 1.5 in number on general-purpose, 2.5 on mixed, and 1.1 on ordinary-tractor plantations. For each tractor on the plantations of each of the three power-type groups, there were respectively 435, 369, and 739 acres of cotton grown.

The hours of use per tractor were the same on general-purpose and on mixed-tractor plantations. The greater total hours of use on the latter group as shown in table 3 was due to the larger number of tractors owned. Tractor work per acre of cotton was lowest on ordinary-tractor plantations with an average of 0.6 hour, which was one-third of the amount done with tractors on the other plantations. Belt work constituted but 0.1 hour per acre of cotton for each of the groups.

The drawbar work done with tractors was not confined strictly to crop production. Ditching, grading, and road work averaged 14 percent of the total drawbar work.

Mules on tractor plantations worked slightly in excess of 1,000 hours per mule annually, with no great variation according to type of plantation. But not all of this was on crops. For fuel hauling alone, 6,300 hours of mule work were required per plantation. Of the total mule work on all tractor plantations 75 percent was for strictly crop operations, 7 percent for road hauling, 5 percent for farm hauling, 12 percent for fuel hauling, and 1 percent for other miscellaneous plantation work. The average total hours of mule work per plantation was 49,460 or 68 hours per acre of cotton. Mule power was used most on the mixed-tractor plantations where it averaged 76 hours per acre of cotton as compared with 73 hours on ordinary, and 64 hours on general-purpose tractor plantations.

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The hours of motor truck work were greatest on ordinary-tractor plantations where more trucks were owned. The cost of truck hire is not included in table 3, but it will be discussed later. The average hours of truck work are not necessarily proportionate to size of the plantation because of differences among plantations in number of trucks owned, in the influence of hiring, and in the use of mules for hauling.

General-purpose tractor plantations were divided into three groups according to cotton acreage. In the low cotton-acreage group, 1.2 tractors and 0.8 truck were owned per plantation and 17.6 acres of cotton were grown per mule; in the medium group 1.3 tractors and 0.4 truck were owned and 15.4 acres of cotton were grown per mule; and in the high cotton acreage group, 2.0 tractors and 0.9 truck were owned and 15.7 acres of cotton were grown per mule. The low tractor utilization in the medium group was accompanied by a similarly low motor truck use because of the small number of trucks owned. Mule hours averaged 863, 986, and 1,055 per mule, respectively, for the different size groups. Mules on the large-acreage group worked nearly 200 hours more per head than those on the small group, notwithstanding an average of almost one more tractor per large plantation. This was because the number of tractors did not increase in proportion to the size of each group. For each tractor owned there were 219 acres of cotton on the small plantations, 407 on the medium plantations, and 592 on the large plantations. It is apparent that tractors, especially those of the general-purpose type, had not been in use sufficiently long to be adequately established in the plantation organization. This is evidenced by the fact that 65 percent of the planters were using tractors for the first time in 1929.

HOURS OF TRACTOR WORK PER TRACTOR

The average annual hours of tractor work per plantation were shown in table 3. Table 4 shows the average hours of work of individual tractors. Type of tractor had a marked effect on the amount of work done; hence the data were sorted to show type influence.

TABLE 4.—*Average number of hours of work per tractor on plantations, classified by power type, 1929*

Size group (cotton acres)	Plantations surveyed	Average cotton acreage	Tractors owned	Work on home plantation			Custom work
				Drawbar	Belt	Total	
GENERAL-PURPOSE TRACTOR PLANTATIONS							
	Number	*Acres*	*Number*	*Hours*	*Hours*	*Hours*	*Hours*
150 to 399	19	265	23	707	24	731	25
400 to 799	27	543	36	646	39	685	14
800 and over	19	1,184	38	722	58	780	17
Total or average	65	649	97	690	43	733	18
MIXED (ORDINARY AND GENERAL-PURPOSE) TRACTOR PLANTATIONS							
Total or average	19	933	48	682	51	733	4
ORDINARY-TRACTOR PLANTATIONS							
Total or average	14	792	15	359	80	439	

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Forty percent of all tractors were used for belt work. The time consumed by this kind of work amounted to 18 percent of the total tractor hours on ordinary-tractor plantations, 6 percent on general-purpose tractor plantations, and 7 percent on the mixed-tractor plantations.

A classification of tractors according to acreage in cotton per tractor and hours of use is shown in table 5. Forty percent of the total of 160 tractors were used less than 500 hours, 43 percent were used from 500 to 1,100 hours, and 17 percent were used 1,100 hours or more.

TABLE 5.—*Tractors classified by number of hours of work per year and acreage of cotton per tractor, 1929*

Cotton acreage per tractor (acres)	Tractors used—								
	Less than 300 hours	300 to 499 hours	500 to 699 hours	700 to 899 hours	900 to 1,099 hours	1,100 to 1,299 hours	1,300 to 1,499 hours	1,500 hours and over	Total
	Number	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*
Less than 100	2	1	1	1			1	1	7
100 to 199	5	8	5	11	10			2	41
200 to 299	1	3	4	2	2			1	13
300 to 399	3	4	3		1	6		4	21
400 to 499	3	4	6		4				17
500 to 599	3	2	3			1			9
600 to 699	6	2	3	1	2	5	2		21
700 to 799	1	3		3				1	8
800 to 899	4	3		2			1	1	11
900 to 999		1		3					4
1,000 and over	3	2		1	1			1	8
Total	31	33	25	24	20	12	4	11	160

FIGURE 2.—Disking beds with a general-purpose tractor and a 5-foot tandem disk. On almost every plantation on which a tractor was owned, it was used for disking.

OPERATIONS FOR WHICH TRACTORS WERE USED

Table 6 shows the number and the percentage of plantations on which specified tractor operations were performed. Flat disking was the only operation for which tractors were used to a marked degree on all types of tractor plantations. The type of tractor had no influence on its use for this operation, as tractors were used for flat disking on from 86 to 89 percent of the tractor plantations in the different power groups. Other drawbar operations performed by tractors, but to a lesser degree, were flat breaking, disking beds, (fig. 2), harrowing, drilling, and mowing. Cultivating was done on 60 percent of the plantations using general-purpose tractors alone, and on 58 percent of the mixed-tractor plantations. Baling hay was the most common belt operation. Grinding feed and sawing wood were the only other belt operations of consequence. On some plantations belt work, such as grinding, sawing, and baling, was done with gasoline engines.

TABLE 6.—*Number and percentage of plantations of different power types on which specified operations were performed with tractor power, 1929*

Operation	General-purpose tractor plantations		Mixed (ordinary and general-purpose) tractor plantations		Ordinary-tractor plantations	
	Number	*Percent*	*Number*	*Percent*	*Number*	*Percent*
Drawbar:						
Flat breaking	19	29	6	32	4	29
Flat disking	57	88	17	89	12	86
Disking beds	33	51	6	32	2	14
Harrowing	24	37	6	32	5	36
Bedding	37	57	11	58	----------	----------
Planting	20	31	7	37	----------	----------
Drilling	12	18	4	21	2	14
Cultivating	39	60	11	58	----------	----------
Mowing	30	46	9	47	2	14
Raking	6	9	2	11	----------	----------
Miscellaneous	20	31	12	63	4	28
Belt:						
Baling	17	26	7	37	5	36
Grinding	8	12	4	21	3	21
Sawing	9	14	5	26	4	28
Threshing	1	2	1	5	1	7
Miscellaneous	7	11	1	5	2	14

MULE-WORK EQUIVALENT OF TRACTOR WORK AND PROPORTION OF TOTAL WORK DONE WITH TRACTORS

The mule-work equivalent of tractor work represents the number of hours of mule work that would have been necessary for doing the work done with tractors. For example, general-purpose tractors were used for an average of 339 acres of flat disking. Flat disking with mules required an average of 2.83 mule-hours per acre. The tractor work, therefore, is the equivalent of 339 multiplied by 2.83, or 959 mule-hours per plantation for flat disking. Adding the number of hours of mule work per plantation to the mule-work equivalent of tractor work gives the total number of hours of mule work required had tractors not been used (table 7). The proportion of the work done by tractors is the percentage the mule-work equivalent is of the total time.

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TABLE 7.—*Mule-work equivalent of tractor work and proportion of total drawbar work done with tractors on plantations, classified by power type, 1929*

Operation	General-purpose tractor plantations				Mixed (ordinary and general-purpose) tractor plantations						Ordinary-tractor plantations			
	Mule work per plantation	Mule-work equivalent of tractor work	Total	Proportion with tractor	Mule work per plantation	Mule-work equivalent of general-purpose tractor work	Mule-work equivalent of ordinary tractor work	Total	Proportion with general-purpose tractor	Proportion with ordinary tractor	Mule work per plantation	Mule-work equivalent of tractor work	Total	Proportion with tractor
	Hours	*Hours*	*Hours*	*Percent*	*Hours*	*Hours*	*Hours*	*Hours*	*Percent*	*Percent*	*Hours*	*Hours*	*Hours*	*Percent*
Flat breaking	731	374	1,105	34	1,355	782	467	2,604	30	18	440	935	1,375	68
Disking, flat	6	959	965	99	30	3,238	1,652	4,920	66	34		1,009	1,009	100
Disking, beds	184	682	866	79		428		428	100		633	27	660	4
Harrowing	94	138	232	59	208	111	80	399	28	20	111	48	159	30
Rolling	18	28	46	61	49			49			54		54	
Bedding	5,333	654	5,987	11	10,682	841		11,523	7		9,327		9,327	
Fertilizing	445	34	479	7	880	83	45	1,008	8	4	716		716	
Total	6,811	2,869	9,680	30	13,204	5,483	2,244	20,931	26	11	11,281	2,019	13,300	15
Planting	1,188	118	1,306	9	2,060	212		2,272	9		1,573		1,573	
Drilling	34	48	82	59	86	17	30	133	13	23	125	9	134	7
Total	1,222	166	1,388	12	2,146	229	30	2,405	10	1	1,698	9	1,707	(1)
Cultivating	16,568	2,480	19,048	13	30,147	1,678		31,825	5		25,272		25,272	
Mowing	95	174	269	65	314	638	16	968	66	2	579	24	603	4
Raking hay to baler	16	26	42	62	166	72		238	30					
Miscellaneous	1,347	6	1,353	(1)	3,202	174	64	3,440	5	2	1,820	83	1,903	4
All other mule hours	2,742		2,742		4,626			4,626			4,544		4,544	
Total	20,768	2,686	23,454	11	38,455	2,562	80	41,097	6	(1)	32,215	107	32,322	(1)
Grand total	28,801	5,721	34,522	17	53,805	8,274	2,354	64,433	13	4	45,194	2,135	47,329	5

[1] 0.5 percent or less.

On each of the two groups of plantations owning general-purpose tractors 17 percent of the total drawbar work on crops was done with tractors. Bedding and cultivating constituted about 70 percent of the total drawbar work on crops. Where none of this was done with tractors, as was the case with the ordinary type, the percentage of the total work done with tractors was necessarily small. Except for disking, tractors were not used for any one operation on practically all plantations. At the time of this study the power take-off mower was replacing mule-drawn mowers on nearly half the plantations having general-purpose tractors.

TRACTOR WORK ON COTTON PRODUCED PRINCIPALLY WITH TRACTOR POWER

Many plantation operators bought tractors in order to lighten the work of their mules by relieving them of the heaviest draft operations such as flat breaking and disking. Others bought them for this purpose and for belt work in addition. Still others bought them for practically all operations in cotton production up to picking. This general use necessitated the purchase of the more adaptable general-purpose type of tractor.

On 24 of the general-purpose tractor plantations, 42 general-purpose tractors were owned. These machines were used in the production of cotton to such an extent that these plantations were selected for special study. The tractors on these 24 plantations were generally used to about the same degree on other crops as on the cotton grown with wage labor.

On each of four plantations, one ordinary two-plow tractor was used to supplement the work done with the general-purpose tractors, thus making a total of 46 tractors on the 24 plantations. On some of the 24 plantations, however, the acreage in cotton was beyond the capacity of the available tractor power, in which case only that portion handled principally with tractors was considered. The acreage of tractor-produced cotton ranged from 40 to 550 acres, and averaged 198 acres per plantation or 103 acres per tractor. The total work done annually by the 46 tractors averaged 937 hours per tractor. This was 230 hours in excess of the average for all tractors.

Tillage practices and type and size of the implements used were variable. The land was flat broken on 10 of the 24 plantations. Disking was done on practically all of the plantations. The 6-foot tandem disk was most generally used. On half of the plantations the cotton acreage was disked twice. Harrowing was done on 12 plantations and bedding on 22 plantations. For the latter operation the 2-row middle-buster was used. Fertilizing was done on 5 plantations with the 4-row planter, which was also used for planting cotton on 16 plantations. In cultivating, 16 plantations used the 4-row, and 8 plantations used the 2-row implement. Cotton was cultivated 15 times on 2 plantations and an average of 9 times on all plantations. Very little dusting was done, yet 2 plantations reported the use of tractors for this operation.

Table 8 shows the time requirement, by operations, for producing an acre of cotton on these 24 plantations, on which the cotton acreage produced principally with tractors averaged 198 acres per plantation. The acreages shown in table 8 represent the average number on which the specified operations were performed, taking into account the number of times each operation was performed.

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TABLE 8.—*Average amount of drawbar work on cotton produced principally with tractor power,*[1] *24 plantations, 1929*

Operation	Tractor work per plantation [2]		Mule work per plantation [2]		Drawbar work per acre [2]	
					Tractor	Mules
	Acres	*Hours*	*Acres*	*Hours*	*Hours*	*Hours*
Flat breaking	33	63	(3)	6	0.3	(4)
Disking, flat, and beds	360	194			1.0	
Harrowing	155	48	6	10	.2	(4)
Bedding	254	174	29	79	.9	0.4
Fertilizing	80	30	35	54	.2	.3
Planting	168	64	34	49	.3	.2
Cultivating	1,649	620	172	471	3.1	2.4
Miscellaneous	26	4	70	151	(4)	.8
Total		1,197		820	6.0	4.1

[1] The average acreage of cotton represented in this table was 198 acres. Cotton acreage worked by tenants principally with mules not included.
[2] Work on cotton acreage only. Does not include tractor work on cotton worked principally by mules.
[3] 0.5 of an acre.
[4] Less than 0.05 hour.

Man labor for tractor work averaged 6.4 hours, and for mule work 2.8 hours per acre of tractor-produced cotton. Planting and fertilizing were the only operations requiring more than one man per tractor.

UTILIZATION OF POWER ON PLANTATIONS WHERE MULES WERE USED

The 63 Delta plantations where mules furnished the power except for some hire of tractors, used an average of 41,509 hours of mule power annually, which is slightly more than one hundred and twelve 10-hour days per mule (table 9). The average number of days of work per mule per year on the small- medium- and large-size plantation groups was about 97 days, 133 days, and 103 days, respectively.

TABLE 9.—*Average annual use of different types of power on mule plantations, classified by size, 1929*

Size group (cotton acres)	Plantations surveyed	Average cotton acreage	Owned power			Hired power		
			Mules	Motor trucks	Miscellaneous	Mules	Tractor	
							Drawbar work	Belt work
	Number	*Acres*	*Hours*	*Hours*	*Hours*	*Hours*	*Hours*	*Hours*
150 to 399	31	263	19,624	333		13	11	10
400 to 799	23	551	48,627	309	14	29	5	
800 and over	9	1,267	98,699	374		2	8	28
Total or average	63	512	41,509	330	5	17	8	9

In the different size groups, from 69 to 78 percent of the mule power was applied to crop work or an average of about 74 percent for all mule plantations. Fuel hauling made up the next largest requirement—from 10 to 11 percent of the total, or 10.7 percent as an average for all mule plantations.

Table 9 also shows the average amount of work by owned motor trucks and the average number of hours of hired mule and tractor work on mule plantations. In addition to the motor-truck work, considerable use was made of mule power for road hauling. This

item averaged 9 percent of the total number of mule-days. The number of days mules were used for miscellaneous hauling operations about the plantations was a little over 4 percent of the total number of days of mule work for the year. Other miscellaneous mule work, as in connection with fence building and garden work, averaged approximately 2 percent of the total.

HOURS OF MULE WORK

On mule plantations and on general-purpose tractor plantations the total number of hours of mule work on the plantation increased with the size of the plantation (table 10). The average crop acreage handled per mule on plantations of the same power type, however, did not vary much. On the general-purpose tractor plantations the crop acreage per mule varied inversely with the acreage in cotton, but the hours of work per mule increased with the size of the plantation. The indications are that the smaller plantations had considerably more power per 100 acres of crops than did the larger plantations.

TABLE 10.—*Average annual hours of mule work per plantation and per mule on plantations classified by power type, 1929*

Size group (cotton acres)	Plantations surveyed	Average cotton acreage	Work stock per plantation	Total crop acreage per animal	Work on plantation		Custom work per plantation
					Per plantation	Per mule [1]	
	Number	*Acres*	*Number*	*Acres*	*Hours*	*Hours*	*Hours*
GENERAL-PURPOSE TRACTOR PLANTATIONS							
150 to 399	19	265	15	24	12,944	860	----------
400 to 799	27	543	35	21	34,510	978	10
800 and over	19	1,184	75	20	79,100	1,052	42
Total or average	65	649	41	21	41,240	1,005	17
MULE PLANTATIONS							
150 to 399	31	263	20	17	19,624	966	1
400 to 799	23	551	37	19	48,627	1,327	----------
800 and over	9	1,267	96	17	98,699	1,033	293
Total or average	63	512	37	18	41,509	1,121	42
MIXED (ORDINARY AND GENERAL-PURPOSE) TRACTOR PLANTATIONS							
Total or average	19	933	66	20	71,291	1,076	56
ORDINARY-TRACTOR PLANTATIONS							
Total or average	14	792	54	20	58,000	1,081	111

[1] Obtained by dividing the total number of hours of work (minus custom work) on all plantations of a given size group by the total number of work stock.

The average crop acreage per mule on each type of plantation did not vary greatly. It was lowest on the mule plantations and highest on the general-purpose tractor plantations. In hours of mule work per mule on the plantation this order was reversed. Work off the plantation was of little consequence, on the average, for table 10 indicates that for only one power-type group, that of ordinary-tractor plantations, did the amount of custom work done with work stock average as much as 100 hours per plantation.

OPERATIONS FOR WHICH MULES WERE USED

In table 11 is shown the average number of hours of annual work done per head of work stock at various drawbar operations. Work stock on mule plantations did the most work per head on the average, whereas those on the general-purpose tractor plantations did the least. The difference amounts to approximately 12 10-hour days per head annually.

On mule plantations, of the total of 112.3 days of work per mule annually spent on all operations, 95.4 days were used directly for crop production. Similarly, work stock on general-purpose tractor plantations averaged 82.2 days per head on crop work out of a total of 100.6 days of all work; work stock on ordinary-tractor plantations averaged 93.7 days per head on crop work of their total of 108.3 days of all work; and on mixed-tractor plantations they averaged 91.3 days of crop work out of a total of 107.7 days of all work.

TABLE 11.—*Average annual hours of mule work* [1] *per head on different operations, 1929*

Operation	Mule work per head on—			
	Mule plantations	General-purpose tractor plantations	Mixed (ordinary and general-purpose) tractor plantations	Ordinary-tractor plantations
Crop work:	*Hours*	*Hours*	*Hours*	*Hours*
Stalk cutting	32	22	24	29
Flat breaking	22	19	20	8
Harrowing	4	2	3	2
Disking, flat, and beds	6	(2)	1	
Laying off rows	1	1	1	1
Bedding	167	132	161	174
Disking beds	7	5		12
Harrowing beds	43	32	48	38
Fertilizing	12	12	14	14
Planting	28	30	33	33
Cultivating, 1-furrow	172	189	229	240
Cultivating, 2-furrow	290	215	226	231
Mowing	6	2	5	11
Raking	3	4	13	7
Hauling loose hay	16	9	8	13
Baling and hauling hay	1	4	4	3
Hauling cotton to gin	126	121	101	94
Hauling corn	16	19	18	20
Miscellaneous crop hauling	1	3	2	2
Miscellaneous crop work	1	1	2	5
Total	954	822	913	937
Other work:				
Hauling manure	8	11	13	10
Hauling fuel on plantation [3]	89	130	127	107
Hauling fuel on road [3]	31	9		8
Miscellaneous hauling on road	10	7	5	3
Miscellaneous hauling on plantation	4	8	9	5
Miscellaneous work	25	18	9	11
Total	167	183	163	144
Grand total	1,121	1,005	1,076	1,081
Hired hauling	1	(2)		
Custom work	1	1	1	2

[1] A few horses were included.
[2] Less than ½ hour.
[3] Wood and coal for plantation use.

Of the total hours of mule work done on all plantations of the four power types, the two operations of bedding (fig. 3) and cultivating required more than one-half. Work stock were used 53.6 days per head for bedding and cultivating on general-purpose tractor plantations, 64.5 days on ordinary-tractor plantations, 61.6 days on mixed-tractor plantations, and 62.9 days per head on mule plantations. It apparently was because of the difference in time spent at bedding and cultivating that mules on the general-purpose tractor plantations worked, on the average, the smallest number of hours per head.

FIGURE 3.—Bedding cotton with two mules and a middle buster. When bedding is done with a two-mule middle buster the rate is about double that accomplished with one mule and a 7- or 8-inch turn plow. The latter requires two furrows to the row.

Aside from bedding and cultivating, mules were used most for hauling fuel (wood and coal), and for hauling cotton to the gin.

HAULING WITH MULES AND WITH MOTOR TRUCKS

Of the total of 161 planters interviewed, 87 had 101 motor trucks which were used, besides mules, for hauling on the plantations, and on the road. Seventy-four planters used mules alone, or hired some hauling done with trucks. Mule and truck utilization for hauling on the road and on the plantations, exclusive of custom work, together with the cost of hired hauling, are shown in table 12.

TABLE 12.—*Average use of mules and motor trucks for hauling, 1929*

Size group (cotton acres)	Plantations surveyed	Average cotton acreage	Motor trucks	Average distance to preferred marketing point	Hauling with motor trucks				Hauling with mules		
					On road		On plantation	Cost of hired hauling	On road		On plantation
					Distance	Time			Distance	Time	
	Number	*Acres*	*Number*	*Miles*	*Miles*	*Hours*	*Hours*	*Dollars*	*Miles*	*Hours*	*Hours*
PLANTATIONS ON WHICH MOTOR TRUCKS WERE OWNED											
150 to 399	30	265	34	9.4	3,717	683	54	2.05	376	1,013	1,916
400 to 799	28	559	31	7.6	3,595	600	27	5.39	1,668	3,389	5,381
800 and over	29	1,123	36	7.6	4,297	836	196	12.90	2,126	3,585	17,836
Total or average	87	646	101	8.2	3,871	707	93	6.74	1,375	2,635	8,338
PLANTATIONS ON WHICH MOTOR TRUCKS WERE NOT OWNED											
150 to 399	29	266	------	4.2	------	------	------	125.07	1,209	2,443	2,470
400 to 799	28	544	------	5.3	------	------	------	177.11	2,262	5,157	8,247
800 and over	17	1,419	------	2.7	------	------	------	264.82	3,873	9,528	14,462
Total or average	74	636	------	4.3	------	------	------	176.86	2,219	5,097	7,411

Mule and motor truck hauling are given in total miles traveled per year and total hours of hauling rather than in ton miles, the best unit for measuring the cost if complete data could have been obtained. It was impossible, however, to obtain data on the sizes of loads. Data were not obtained on all classes of hauling but they include the hauling of such items as feed, seed, fertilizer, fuel, laborers, plantation supplies, and cotton to the gin and the warehouse.

The records do not show why planters bought motor trucks, but evidently distance from market was important. The plantations on which trucks were not owned averaged 4.3 miles and those on which trucks were owned averaged 8.2 miles from their preferred marketing points, or a difference of 7.8 miles per round trip. Hard roads in the Delta allow heavy loads to be hauled quickly with trucks but they hurt the feet of mules.

On the plantations on which motor trucks were not owned, road hauling required about 510 days of mule work, or about 2.3 mule-hours per mile, including time for loading and unloading and for waiting at the gin with cotton. As the number of acres in cotton increased, the total miles of hauling increased as did the expense for hired truck hauling; but there was no relation between miles of hauling and acres in cotton, because of differences in miles the different groups of plantations were from gin and market.

On all plantations where motor trucks were owned, road hauling with trucks required about 71 days per plantation, and with mules about 264 days, which was 246 days less than on the mule plantations.

For both groups of plantations differences occur among plantations in the total miles of annual road hauling because of the location of cotton gins. On many plantations, especially the larger ones, the gin was on the plantation, which reduced the miles of road hauling as compared with plantations not having gins.

ACCOMPLISHMENT OF TRACTORS AND MULES ON DIFFERENT OPERATIONS

Of the various factors influencing the power requirements for crops on cotton plantations, size and type of implements form one over which the planter can exercise control. The greatest efficiency can be effected by selecting implements to fit local conditions and available power units. Obsolete equipment is frequently used with a consequent reduction in the effective use of the power unit. Certain implements purchased for mules (fig. 4) are used, after the purchase of a

FIGURE 4.—Disking cotton beds with two mules and a 3-foot disk. Such a disk is satisfactory with mules but is wasteful if used with a tractor.

tractor, until worn out. This may occasionally be necessary or wise in the case of certain machines like tandem disk harrows, but planters who use unrelated mechanical power and equipment should not expect the results that are obtained by others who have coordinated outfits.

That loss of time and added expense often result from the use of machines not adapted to the power unit is well illustrated by the dusting operation as performed on two of the plantations. On one plantation a general-purpose tractor was used for pulling a three-row cotton duster designed for mules. This outfit had an hourly perform-

ance of about 2 acres, or 21 acres in a 10-hour day, and a fuel and oil cost of 10.7 cents per acre or $2.25 per day. On the other plantation the same type of tractor was used with a 50-row power duster. The hourly performance of this outfit was about 44 acres, or 444 acres in a 10-hour day, and the fuel and oil cost was about 0.8 cent per acre or $3.47 per day. For the outfit on the first plantation to have done the work accomplished in 1 day by that on the second plantation, 21 days and an outlay of about $47.65 for fuel and oil would have been required. With wages for a tractor operator at $2.06 per day, the average rate paid at the time the records were obtained, there would have been a labor charge of $43.26, thus making a total cost for fuel, oil, and labor of $90.91 for the first plantation for doing the same work as was done on the second by 1 operator and 2 helpers at a total cost of $7.53 for fuel, oil, and labor.

A record was obtained for each crop showing the rate of work for each operation on the day basis. The accomplishment is stated in hours, however, because the length of the work day is dependent on the season of the year and on plantation management. Table 13 shows the average rates of accomplishment in acres per hour for general-purpose and ordinary 2- and 3-plow tractors for different operations with different sizes and types of implements. Only those operations are shown which were performed with the various types of tractors and implements on a sufficient number of plantations to give a reliable average.

TABLE 13.—*Accomplishment in acres per hour by tractors on different farming operations, 1929*

Operation and type of tractor	Size and type of implement	Acreage per hour	Operation and type of tractor	Size and type of implement	Acreage per hour
Flat breaking:		*Acres*	Flat harrowing—Con.		*Acres*
General-purpose	2-disk plow	0.55	Ordinary 2-plow	11- to 14-foot drag harrow.	4.58
Flat disking:			Bedding:[1]		
General-purpose	5- to 6-foot tandem disk.	1.75	General-purpose	2-row middle buster	1.40
Ordinary 2-plow	do	1.76	Disking beds:[1]		
General-purpose	7- to 8-foot tandem disk.	1.96	General-purpose	5- to 6-foot tandem disk.	1.74
Ordinary 2-plow	do	1.56	Do	7- to 8-foot tandem disk.	1.97
Ordinary 3-plow	do	2.36	Planting:[1]		
Flat disking in combination:			General-purpose	4-row planter	2.75
General-purpose	5- to 6-foot tandem disk.	1.62	Drilling:		
Ordinary 3-plow	8-foot tandem disk	2.60	General-purpose	6- to 8-foot drill	1.75
Flat harrowing:			Fertilizing:[1]		
General-purpose	9- to 10-foot drag harrow.	2.42	General-purpose	4-row distributor	3.12
Ordinary 2-plow	do	2.14	Cultivating:[1]		
Ordinary 3-plow	do	3.34	General-purpose	2-row cultivator	1.78
General-purpose	11- to 14-foot drag harrow.	4.54	Do	4-row cultivator	3.08
			Mowing:		
			General-purpose	7-foot mower	1.98

[1] The rates given are for cotton in rows from 36 to 42 inches apart.

The average rates of accomplishment in acres per hour for mules on different operations with various sizes and types of implements are shown in table 14.

TABLE 14.—*Accomplishment in acres per hour by teams of mules on different farming operations, 1929*

Operation and width of row	Size and type of implement	Mules per team	Acreage per team-hour
		Number	*Acres*
Stalk cutting	1-row stalk cutter	2	0.84
Do	2-row stalk cutter	3	1.63
Flat breaking	7- to 8-inch plow	2	.14
Do	9- to 10-inch plow	2	.17
Flat disking	5- to 6-foot single disk	4	1.04
Do	7- to 8-foot single disk	4	1.23
Flat harrowing	5- to 6-foot drag harrow	2	1.12
Do	7- to 8-foot drag harrow	2	1.42
Do	do	3	1.45
Laying off rows:			
36 to 42 inches	Single-shovel plow	1	.71
Bedding, 1 furrow:			
36 to 42 inches	10- to 12-inch middle buster	2	.64
44 to 48 inches	10-inch middle buster	2	.74
36 to 42 inches	14-inch middle buster	2	.62
Do	14- to 16-inch middle buster	4	.61
Bedding, 2 furrows:			
36 to 42 inches	7- to 8-inch plow	1	.30
Do	7- to 10-inch plow	2	.35
Harrowing beds:			
36 to 42 inches	1-row drag harrow	1	.67
44 to 48 inches	do	1	.69
36 to 42 inches	5- to 6-foot drag harrow	2	1.04
Do	7- to 8-foot drag harrow	2	1.22
Do	do	3	1.22
Do	do	4	1.36
Do	9- to 10-foot drag harrow	2	1.46
Do	do	3	1.48
Do	10- to 12-foot drag harrow	4	2.02
Disking beds:			
36 to 42 inches	3- to 4-foot single disk	2	.73
Do	do	4	.74
Fertilizing:			
36 to 42 inches	1-row distributor	1	.65
44 to 48 inches	do	1	.71
36 to 42 inches	2-row distributor	2	1.49
Planting:			
36 to 42 inches	1-row planter	1	.63
44 to 48 inches	do	1	.68
36 to 42 inches	2-row planter	2	1.29
Drilling	6- to 8-foot drill	2	.93
Do	do	4	1.11
Cultivating, 1 furrow:			
36 to 42 inches	1-mule cultivator	1	.59
44 to 48 inches	do	1	.68
36 to 42 inches	2-mule cultivator	2	.64
44 to 48 inches	do	2	.69
36 to 42 inches	2-row cultivator	3	1.04
Do	do	4	1.44
Cultivating, 2 furrows:			
36 to 42 inches	1-mule cultivator	1	.31
44 to 48 inches	do	1	.35
Mowing	4½-foot mower	2	.67
Do	5- to 5½-foot mower	2	.70
Do	6-foot mower	2	.89
Raking	8- to 9-foot dump rake	2	1.40
Do	10-foot dump rake	2	1.59
Do	Side-delivery rake	2	1.27
Binding:			
36 to 42 inches	1-row binder	3	.54

Variations in rates of work for mule operations on different plantations due to size of team and type, size, and condition of implement, although not so great as for tractor operations, do show that in some instances economies could have been effected in man labor and mule work by the use of different combinations of mules and implements by means of the multiple hitch. Stalk cutting is an operation that

illustrates variations in performance with different sized mule outfits. With 2 mules and a one-row stalk cutter, the average rate for the plantations reporting was 0.42 acre per mule per hour. For 2-row 3-mule outfits, the number of acres per hour was nearly double and the rate per mule per hour showed an increase of about 29 percent.

The rate of accomplishment of tractors and mules on the same operation in some cases were widely different. General-purpose tractors pulling 5- to 6-foot tandem disks, double-disked an average of 1.75 acres per hour or about 68 percent more than was disked twice with two 4-mule teams on two 5- to 6-foot single disks. The ordinary 3-plow tractors pulling 7- to 8-foot tandem disks covered, on the average, about 92 percent more acres than were disked twice with two 4-mule teams on two 7- to 8-foot single disks. Bedding in 36- to 42-inch rows with 2 mules and a 10- to 12-inch middle buster (fig. 3)

FIGURE 5.—Two-row middle buster mounted on a general-purpose tractor. With a 2-row tractor middle buster one operator can bed about 14 acres in a 10-hour day.

was done at a rate of 0.64 acre per hour or 1.28 acres per hour with two outfits, whereas with a general-purpose tractor and a 2-row middle buster (fig. 5), the rate was 1.40 acres per hour or 9 percent greater than with 2 mule-drawn middle busters.

Planting with 2 mules and a 2-row planter in 36- to 42-inch rows (fig. 6) was done at a rate of 1.29 acres per hour. With a general-purpose tractor the rate with a 4-row planter was 2.75 acres per hour or 113 percent greater (fig. 9). With two 2-mule outfits a total of 2.58 acres would have been planted per hour or a difference in favor of the tractor of about 7 percent. For fertilizing, the percentage difference was about the same as for planting although the rate per hour for both types of power was somewhat higher. Based on a few reports, cultivating with 3 or 4 mules and a 2-row cultivator showed a rate of 1.04 and 1.44 acres per hour, respectively. Acres per mule per hour for either outfit was practically the same. With a general-purpose tractor and a 2-row cultivator the rate was 1.78 acres per

hour or about 24 percent greater than with the mule team and a 2-row cultivator. The 4-row tractor outfit doing 3.08 acres per hour was about 73 percent faster than the 2-row tractor outfit and about 7 percent faster than two 2-row cultivators each drawn by 4 mules.

The rate of accomplishment for 4½- and 6-foot mowers, drawn by two mules, was about 0.15 acre per hour per foot of cutter-bar width. The rate for the 7-foot tractor-drawn mower was 0.28 acre per hour per foot of width, or about 87 percent greater than for the mule-drawn outfits.

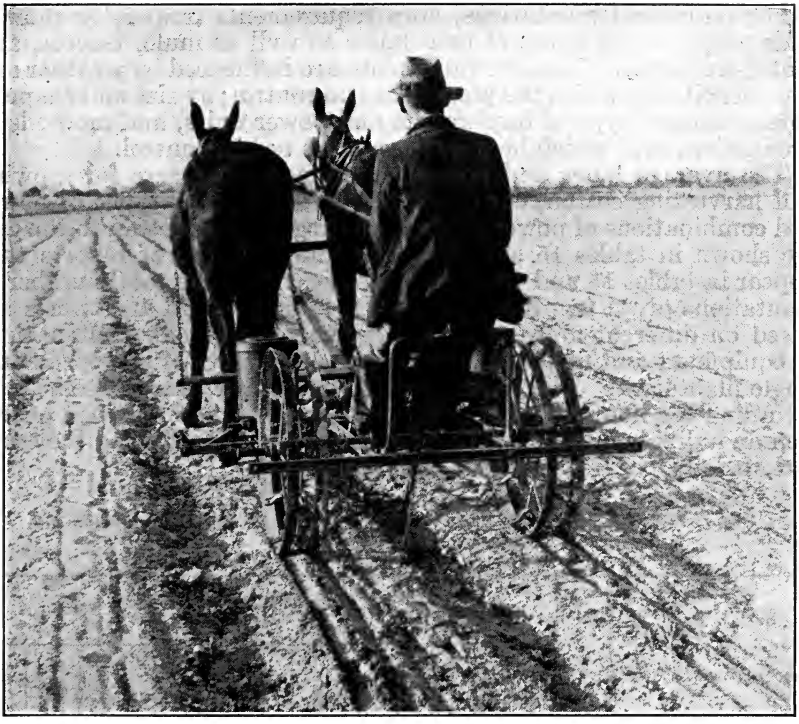

FIGURE 6.—Planting cotton with mules and a 2-row planter. On mule and on ordinary-tractor plantations, mules furnished all of the power for planting and on plantations on which general-purpose tractors were owned, they furnished 91 percent of such power. With a 2-row planter about 13 acres can be planted in a day as compared with about 6 acres with a 1-row outfit.

POWER REQUIREMENTS FOR PRODUCING CROPS

Of the factors entering into the cost of producing a crop, labor and power constitute the principal items. Of the factors responsible for high productivity and high standards of living among agricultural workers, machinery is perhaps the most important, for without machinery, animal and mechanical power would be of little value. With modern equipment and practices, some planters have reduced the labor requirements for producing cotton to but a small fraction of what they were before the introduction of the general-purpose tractor or multiple hitches for mule teams. Although many planters had demonstrated to their own satisfaction that labor requirements can be drastically reduced, only a few Delta plantations were completely

mechanized. Contributing to this situation are a number of factors characteristic of the South. The tenant or cropper system of producing cotton has been practiced for nearly 70 years. This system operates only with small units. Nor can any radical labor-saving change be profitably made so long as cotton is chopped and picked by hand, since workers are maintained on the plantation throughout the year especially to perform this work. Although it is possible to produce cotton with present equipment without the necessity of hand chopping, the lack of a mechanical cotton picker has caused planters to continue to keep most of their tenants.

For individual plantations, crop requirements frequently show a wide range in the hours of man labor as well as mule, tractor, and motor-truck use. These requirements are influenced by weather and type of soil over which the planter has no control; by size and shape of fields, size and type of implements and power units, and methods of production, over which he does have more or less control.

The average labor and power requirements per acre for growing and harvesting cotton, corn, and hay with different types of power and combinations of power types, including hauling cotton to the gin, are shown in tables 15 and 16. The total number of reports that appear in tables 15 and 16 are not identical with the total number of plantations given in other tables. In tables 15 and 16 reports are based on different areas of cotton grown by different combinations of equipment and methods, and two or more cases often represent a single plantation. The requirements shown are those obtained by recording the hours of labor and power used per acre for each operation on individual fields. The time consumed in producing the crops included that of men, women, and children.

TABLE 15.—*Hours of labor and power used per acre for growing, harvesting, and hauling cotton to gin, 1929*

Principal power type used	Reports	Preharvest				Harvesting and hauling			Total			
		Man labor	Mule work	Tractor-drawbar work	Motor-truck work	Man labor	Mule work	Motor-truck work	Man labor	Mule work	Tractor-drawbar work	Motor-truck work
36- to 42-inch rows:	*No.*	*Hr.*	*Hr.*	*Hr.*	*Hr.*	*Hr.*	*Hr.*	*Hr.*	*Hr.*	*Hr.*	*Hr.*	*Hr.*
Mules	94	76.1	46.8	------	------	113.9	8.7	0.2	190.0	55.5	------	0.2
General-purpose tractors[1]	24	40.7	4.3	6.0	(2)	76.8	4.6	.8	117.5	8.9	6.0	.8
General-purpose tractors and mules	40	64.6	38.7	.6	(2)	108.5	7.0	.3	173.1	45.7	.6	.3
44- to 48-inch rows:												
Mules	11	90.1	43.6	------	------	98.6	6.2	.1	188.7	49.8	------	.1

[1] A small amount of mule labor was used.
[2] Less than 0.05 hour.

The total hours of man labor for producing cotton in 36- to 42-inch rows almost entirely with general-purpose tractors were 62 percent of those when mules were used exclusively. There was only 16 percent as much mule work on the tractor-produced as on the mule-produced cotton. The small amount of labor used for harvesting

and hauling the tractor-produced cotton was because of differences in yield, type of labor, and the greater use of trucks for hauling to the gin. The requirements for cotton produced with a combination of general-purpose tractor and mule power were not a great deal lower than those for cotton produced with mules alone, because the tractors were used for only a few operations. Mule-produced cotton grown in 44- to 48-inch rows required slightly less man labor and mule work than that grown in 36- to 42-inch rows.

With some reasonable adjustments made for chopping and hoeing on the basis of 1 acre per day per worker, and picking on the basis of 125 pounds per day per worker, the total labor requirements for mule-produced cotton in 36- to 42-inch rows would be reduced to 175 hours per acre, general-purpose tractor-produced cotton to 114 hours, and general-purpose tractor and mule-produced cotton to 153 hours per acre. For the first and third groups practically all of the reduction is due to the change in the picking rate, while in the second, hoeing accounted for all but about three-quarters of an hour. With the same adjusted hoeing rate and a picking rate of 150 pounds per day, the total requirements would be 159, 102, and 139 hours per acre, respectively. Mule-produced cotton in 44- to 48-inch rows with the same adjustments show a total labor requirement of 140 hours with a picking rate of 125 pounds, and 127 hours with a picking rate of 150 pounds of cotton per day.

TABLE 16.—*Hours of labor and power used per acre for growing and harvesting corn and hay, 1929*

Crop and principal power type used	Reports	Man labor	Mule work	Tractor-drawbar work	Tractor-belt work	Motor-truck work
	Number	*Hours*	*Hours*	*Hours*	*Hours*	*Hours*
Corn standing alone:						
36- to 42-inch rows:						
Mule	55	42.4	42.8			
General-purpose tractor and mule	33	36.1	29.1	2.2		
Mixed-tractor and mule	11	32.2	34.7	1.5		
Ordinary-tractor and mule	9	32.3	32.5	1.4		
44- to 48-inch rows:						
Mule	13	40.7	43.1			
Corn with interplanted crops:						
36- to 42-inch rows:						
Mule	20	43.6	39.6			
General-purpose tractor and mule	9	36.6	38.3	1.4		
Hay:						
Alfalfa loaded by hand from windrow:						
Mule	35	6.5	8.9			
Mixed-tractor and mule	8	5.1	5.2	.6		
Alfalfa bunched and loaded by hand:						
Mule	9	8.0	8.0			
Mixed-tractor and mule	7	5.9	5.4	.6		
Alfalfa baled from windrow:						
Mule	5	11.8	9.7		0.7	
Mixed-tractor and mule	7	5.9	4.2	.5	.4	0.2
Oats loaded by hand from windrow:						
Mixed-tractor and mule	10	12.6	14.2	1.7		
Soybeans broadcast and loaded from windrow:						
Mule	14	24.8	40.7			
Mixed-tractor and mule	18	23.2	26.8	2.2		
Soybeans baled from windrow:						
Mixed-tractor and mule	14	21.2	13.4	2.4	1.1	.04
Sorghum broadcast and loaded from windrow:						
Mule	15	18.2	29.7			
Mixed-tractor and mule	11	14.2	13.9	2.0		
Cowpeas broadcast and loaded from windrow:						
Mixed-tractor and mule	6	15.2	14.1	2.2		

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In the production of corn the hours of man labor were higher in every instance where mules were used for power exclusively than they were where tractors and mules were used. For corn planted in 36- to 42-inch rows, man labor with a general-purpose tractor and mules was higher than it was for the other two power types including a tractor. This was because of the use of 2 or 3 men for certain tractor operations on which mules and 1 man were used in the other groups. Rates for alfalfa hay were lower than for the other hay crops because no time was included for preparing, seeding, and cultivating as was the case with the annual hay crops. Because of early cultivating of soybean and sorghum hay, which was not done in the case of oat and cowpea hay, the requirements of the former were considerably higher. The tractors used on the hay crops were not separated by type because the operations and rates of performance for all were practically the same.

The average figures that appear in tables 15 and 16 are more indicative of normal requirements in the area surveyed than would be figures for individual plantations on which requirements might be extremely high or low. The average figures overcome the influence of variations in weather, soil, equipment, size and shape of fields, and other differences that occurred on the different plantations included in the survey. Individual plantation figures on the other hand, reflect the favorable or unfavorable conditions on the particular plantation. Individual plantation figures are of interest, however, as they show what was done under given conditions for a particular year.

Such figures show extremely wide differences among individual plantations in labor requirements as illustrated by the following comparison of two plantations similar in soil type and other general features. On plantation no. 1, with 210 acres of tractor-produced cotton, the crop was carried to picking time with only 12.9 hours of man labor, 8.8 hours of tractor work, and approximately 0.2 hour of truck work per acre. The yield was 436 pounds of lint cotton per acre. On plantation no. 2, with 410 acres in cotton, 90 man-hours, 2.8 mule-hours, and 6.1 tractor-hours per acre were used to picking time. The yield was 426 pounds. The question as to why it took 77.1 less man-hours per acre on plantation no. 1 than on plantation no. 2 is answered by the condition of the land, which on the latter was weedy because of having been flooded. The crop on plantation no. 1 was cultivated 4½ times with a rotary hoe, 8 times with a 4-row tractor cultivator, and was hoed by hand once. On plantation no. 2 there were 10 cultivations with a 4-row cultivator and in addition the crop had to be hoed by hand 8 times. On plantation no. 2 the additional hoeing and added man labor for mule operations (which on plantation no. 1 were performed with a tractor or truck) account almost entirely for the big difference in the per-acre man-labor requirements.

Striking differences were found also on mule plantations. On plantation no. 3, with 900 acres of cotton yielding 467 pounds of lint per acre, the crop was carried to picking with 64.9 man-hours and 34.8 mule-hours per acre. On plantation no. 4 with 2,600 acres of cotton yielding 422 pounds of lint per acre, 116.1 man-hours and 43.1 mule-hours were used per acre. For man labor the difference was 51.2 hours per acre and for mule labor it was 8.3 hours per acre. Thus the man-hours and the mule-hours used on plantation no. 4 exceeded those used on plantation no. 3 by 79 and 24 percent, respectively.

Cultivation was again responsible for the difference in requirements. On plantation no. 3 the crop was hoed by hand 3 times and all cultivations, 6 in number, were done with 2-mule 1-row cultivators (fig. 7), thus eliminating the separate working of the middles. On plantation no. 4 hoeing was done 4 times and there were 7 cultivations, most of which were done with 1-mule outfits, necessitating 2 furrows to the row and 1 furrow to the middle as compared with one operation to the row on the other plantation. The small difference in mule hours as compared with man hours was due to the use of 3- and 4-mule teams on several operations on plantation no. 4 while on plantation no. 3, 2-mule outfits were the largest used.

Had the low labor requirements of plantations no. 1 and no. 3 been realized on plantations no. 2 and no. 4 it would have greatly reduced

FIGURE 7.—Cultivating cotton with a 1-row walking cultivator. With a 1-row, 2-mule cultivator about twice as many acres can be cultivated in 1 day as with the common 1-mule outfit when going only twice to the row.

the cost. Plantation no. 2, with 410 acres of tractor-produced cotton on the basis of 12.9 man-hours per acre, would have saved 3,161 man-days which at, say 75 cents per day, would have amounted to $2,371 or about $5.78 per acre. Plantation no. 4 with 2,600 acres of mule-produced cotton on the basis of 64.9 man-hours per acre would have saved 13,312 man-days which at the same rate would have amounted to $9,984 or about $3.84 per acre.

COST OF POWER

The data gathered in this survey were used as the basis for estimating the approximate cost of farm power on delta plantations. In interpreting these estimated figures it should be kept in mind that costs vary from plantation to plantation and from year to year. One reason for calculating costs is to reveal the causes of the variation

found, particularly as related to the different types of power used, the different farm practices followed, and the varying size of plantations.

COST OF USING TRACTORS

Tractor-operating costs include the variable costs of fuel, lubricants, chore labor, repairs and repair labor, and the fixed costs of depreciation and interest. Table 17 shows the average annual operating cost per tractor, the cost per hour, and the percentage each item of cost was of the total cost in 1929.

TABLE 17.—*Average cost of using a tractor on plantations classified according to power type, 1929* [1]

Item	General-purpose tractor plantations			Mixed (ordinary and general-purpose) tractor plantations			Ordinary-tractor plantations		
	Cost		Proportion of all costs	Cost		Proportion of all costs	Cost		Proportion of all costs
	Per year (733 hours)	Per hour used		Per year (733 hours)	Per hour used		Per year (439 hours)	Per hour used	
	Dollars	*Dollar*	*Percent*	*Dollars*	*Dollar*	*Percent*	*Dollars*	*Dollars*	*Percent*
Fuel [2]	186.49	0.255	38.4	190.51	0.260	36.7	148.06	0.337	32.6
Oil [3]	33.32	.046	6.9	34.27	.047	6.6	26.98	.062	5.9
Grease [4]	4.13	.006	.9	3.86	.005	.7	3.69	.008	.8
Chore labor [5]	10.82	.015	2.2	9.62	.013	1.9	7.60	.017	1.7
Repairs and expert labor, in cash	42.22	.057	8.7	66.21	.090	12.8	81.97	.187	18.1
Plantation repair labor [5]	.32	--------	.1	.31	.001	.1	.28	.001	.1
Total variable cost	277.30	.378	57.2	304.78	.416	58.8	268.58	.612	59.2
Depreciation [6]	179.63	.245	37.0	186.61	.255	36.0	158.97	.362	35.0
Interest [7]	28.21	.039	5.8	27.10	.037	5.2	26.50	.061	5.8
Total fixed cost	207.84	.284	42.8	213.71	.292	41.2	185.47	.423	40.8
Total costs [8]	485.14	.662	100.0	518.49	.708	100.0	454.05	1.035	100.0

[1] See table 31 and figure 10 for changes in prices since 1929.
[2] Fuel at average prices per gallon at plantation—17.3 cents for gasoline and 12.2 cents each for kerosene and fuel oil.
[3] Oil at average prices per gallon at plantation—61.6 cents for motor oil and 94.3 cents for transmission oil.
[4] Grease at average price of 12.3 cents per pound at plantation.
[5] Chore labor and plantation repair labor at average price of 20.6 cents per hour of labor.
[6] Annual charge per machine based on estimated life.
[7] Annual charge per machine based on 6 percent of one-half first cost.
[8] Not including shelter, taxes, or insurance for tractor or wages for operator.

The average operating cost of all tractors irrespective of type was $492 per year and 70 cents per hour, based on an average of 705 hours of operation. Annual operating costs were comparatively low for tractors on ordinary-tractor plantations; but, because of the low number of hours of usage, the cost per hour was much higher than was the cost for those on the other tractor plantations. This illustrates a point of economy frequently overlooked by operators. Maximum use means minimum fixed charges, or "overhead", per unit of service.

Variable costs for different types of tractors were from 57 to 59 percent and fixed costs from 41 to 43 percent of the total operating

cost. Fuel and lubricants for all tractors averaged about 45 percent of the total operating cost. Repairs for tractors fluctuated sharply on the three types of plantations, but were in the same order as the relative average ages of the tractors. Tractors on general-purpose tractor plantations had been used 1.8 years on the average and repairs amounted to approximately 6 cents per hour of operation, while those on ordinary-tractor plantations had been used 4.5 years and repairs were approximately 19 cents per hour of operation. On 42 of the 65 general-purpose tractor plantations, the operators had not owned tractors before. Repairs on the tractors on those plantations averaged $55.66 per tractor annually or 7 cents per hour compared with $29.05 annually or 4 cents per hour on plantations on which tractors previously had been owned.

FIRST COST, AGE, AND ESTIMATED LIFE OF TRACTORS

On the plantations surveyed, tractor experience began in 1915, with two tractors in use. After 1915 the increase was not significant until 1922 when 10 operators bought tractors. There was no further marked increase until 1927 when the influence of the general-purpose tractor became noticeable. Of the 98 tractor-plantation operators, 50 were using tractors for the first time in 1929, and 42 were operating solely with the general-purpose type.

The two-plow ordinary type tractors considered in this survey had been used an average of 4.8 years in 1929. Individual ages ranged from 2 to 8 years, but most of the tractors were from 3 to 5 years old. The three-plow tractors had been used an average of 3.5 years, and 8 of the 14 had been used less than 4 years. The general-purpose tractors had been used an average of 1.8 years, and 100 of the 125 had been used 2 years or less. Tractor experience in the Delta was too short and too limited in 1929 to serve as a dependable basis for estimating normal length of service.

FUEL AND LUBRICANTS USED IN TRACTORS

Kerosene was used on 49 of the 98 tractor plantations, gasoline on 36, fuel oil on 11, and various kinds of fuels were used on 2. The average quantities of fuel and lubricants used by tractors annually and per hour of operation are shown in table 18. Consumption by individual tractors varied according to the ability of the operator, the age and condition of the tractor, type of soil, and the loads pulled. On the average each tractor used 1,274 gallons of fuel, 52 gallons of oil, and 33 pounds of grease during the year. Of the total amount of fuel, 94 percent was used for drawbar operations and 6 percent for belt operations. The average rate of consumption per hour for drawbar work was 1.8 gallons and for belt work 1.7 gallons. For all tractors the consumption of oil per hour of operation averaged 0.07 gallon. For each gallon of oil an average of 25 gallons of fuel was consumed. The yearly fuel requirements per plantation for all tractors averaged 2,080 gallons.

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TABLE 18.—*Quantities of fuel and lubricants used per tractor for work on plantations, 1929* [1]

Kind of work and type of tractor used	Average quantity used—								
	Per year						Per hour		
	Fuel				Oil	Grease	All fuels	Oil	Grease
	Gasoline	Kerosene	Fuel oil	Total					
Drawbar work:	*Gallons*	*Gallons*	*Gallons*	*Gallons*	*Gallons*	*Pounds*	*Gallons*	*Gallon*	*Pound*
General-purpose	522	568	142	1,232	49.6	31.6	1.79	0.072	0.046
Mixed (ordinary and general-purpose)	493	537	207	1,237	50.1	29.2	1.82	.074	.043
Ordinary	480	313	-------	793	34.8	24.5	2.21	.097	.068
Belt work:									
General-purpose	34	28	1	63	2.8	2.0	1.48	.065	.046
Mixed (ordinary and general-purpose)	67	15	9	91	3.7	2.2	1.77	.073	.043
Ordinary	120	49	-------	169	7.0	5.5	2.11	.087	.068

[1] Does not include custom work.

The improper use of primary fuels in tractors frequently leads to trouble and unnecessary expense, unless caution is exercised. A tractor designed for any one fuel will not function at maximum efficiency with another fuel because of the difference in compression ratios.

Gasoline is used for starting all tractors because it vaporizes at a lower temperature than do other fuels and because it can be used without preheating. The change from gasoline after starting to other fuels should not be made before the engine is thoroughly hot, so that good combustion will be insured. The final adjustment of the needle valve should not be made until the engine has reached its optimum temperature. Mixtures too rich should be avoided to prevent crankcase dilution, carbon deposits, fouling of spark plugs, and excessive fuel consumption.

COST OF USING TRACTOR-DRAWN IMPLEMENTS

In table 19 are shown the costs incident to the use of the more important tractor-drawn implements which were especially designed for use with tractors. All of the implements, especially the disk harrow and the cultivator, were owned on plantations in different numbers. Disking greatly exceeded any other drawbar operation on the plantations and middle busting was more prevalent than plowing. There was an equal number of 2-row and 4-row cultivators. The figures in table 19 on cost and annual accomplishment are based on records of individual implements.

TABLE 19.—*Cost of using specified tractor-drawn implements, 1929* [1]

Implement and size	Depreciation	Interest	Repairs	Total		
				Per year	Per acre	Per hour
	Dollars	*Dollars*	*Dollars*	*Dollars*	*Dollar*	*Dollar*
Plow, 2-disk	17.57	3.69	3.16	24.42	0.19	0.10
Disk harrow, 5- to 8-foot tandem	20.82	3.81	7.27	31.90	.08	.15
Middle buster, 2-row	15.38	3.00	3.96	22.34	.11	.15
Mower, 7-foot	18.79	3.27	6.04	28.10	.13	.25
Planter, 4-row	33.97	6.42	2.44	42.83	.15	.42
Cultivator, 2-row	19.55	3.99	7.87	31.41	.05	.08
Cultivator, 4-row	48.11	7.65	8.57	64.33	.05	.15

[1] See table 31 and figure 10 for changes in costs since 1929.

The annual cost of using such implements ranged from $22 for middle busters to $64 for four-row cultivators. Differences in first cost, estimated life, and repairs account for the extreme differences in annual cost.

High annual machinery costs should be closely watched by the operator. Although most of the annual cost is not an immediate actual cash cost during the useful life of the machine, it surely must be reckoned as such at the time the machine must be replaced. The amount of work to be done generally determines the economy of ownership of a machine. A good example of this is apparent in the cost per acre of the 2-row and the 4-row cultivators. Although the annual cost of the 4-row cultivator may exceed that of the 2-row machine by 100 percent, it may function at the same cost per acre as the smaller

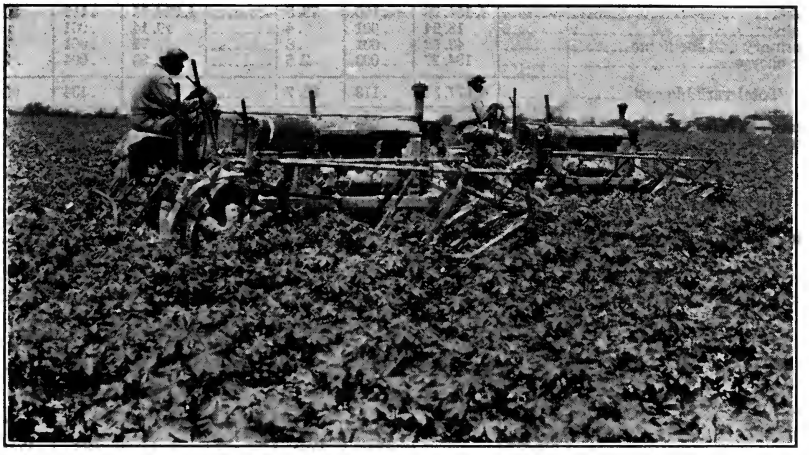

FIGURE 8.—Cultivating cotton with two 4-row tractor cultivators. The 4-row tractor cultivator will handle twice the acreage covered by a 2-row outfit in about the same time.

machine or at lower cost. A total of 696 acres per machine was handled by the 2-row and 1,276 acres by the 4-row cultivator with but an additional 6 percent in time requirement (fig. 8).

COST OF USING MULES

The factors included in estimating the yearly and hourly cost of mule work on different types of plantations, the charges attributable to each in 1929, and the percentage that the cost of each was of the total cost are shown in table 20. The net costs for mule work shown in this table are comparable to the total costs for tractor work shown in table 17. The unit charges, except those for manure, are the average value of the items as obtained from planters' estimates. For manure, the value was estimated by members of the staffs of the cooperating experiment stations.

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TABLE 20.—*Average cost per plantation of keeping mules on the plantations, classified according to power type, 1929*[1]

Item	Mule plantations				General-purpose tractor plantations			
	Number per year	Cost per plantation			Number per year	Cost per plantation		
		Per year	Per mule-hour	Percentage of total		Per year	Per mule-hour	Percentage of total
		Dollars	*Dollar*	*Percent*		*Dollars*	*Dollar*	*Percent*
Mules per plantation	37				41			
	Mule-hours				*Mule-hours*			
Work on the plantation	41, 509				41, 240			
Chore labor [2]		325. 60	0. 008	6. 2		360. 90	0. 009	5. 9
Feed [3]		4, 154. 98	. 100	78. 8		4, 928. 05	. 119	80. 5
Shoeing		18. 94	. 001	. 4		19. 14	. 001	. 3
Veterinary and medicine		43. 52	. 001	. 8		49. 72	. 001	. 8
Gear charge		134. 27	. 003	2. 5		161. 33	. 004	2. 7
Total variable cost		4, 677. 31	. 113	88. 7		5, 519. 14	. 134	90. 2
Depreciation [4]		356. 18	. 008	6. 8		299. 52	. 007	4. 9
Interest [5]		239. 21	. 006	4. 5		300. 51	. 007	4. 9
Total fixed cost		595. 39	. 014	11. 3		600. 03	. 014	9. 8
Total costs [6]		5, 272. 70	. 127	100. 0		6, 119. 17	. 148	100. 0
Manure credit [7]		93. 31	. 002			103. 43	. 002	
Net cost [6]		5, 179. 39	. 125			6, 015. 74	. 146	

Item	Mixed (ordinary and general-purpose) tractor plantations				Ordinary-tractor plantations			
	Number per year	Cost per plantation			Number per year	Cost per plantation		
		Per year	Per mule-hour	Percentage of total		Per year	Per mule-hour	Percentage of total
		Dollars	*Dollar*	*Percent*		*Dollars*	*Dollar*	*Percent*
Mules per plantation	66				54			
	Mule-hours				*Mule-hours*			
Work on the plantation	71, 291				58, 000			
Chore labor [2]		582. 62	0. 008	5. 6		471. 65	0. 008	5. 9
Feed [3]		7, 870. 46	. 111	75. 7		6, 188. 85	. 107	78. 1
Shoeing		22. 21	. 2			38. 50	. 001	. 5
Veterinary and medicine		145. 32	. 002	1. 4		94. 70	. 002	1. 2
Gear charge		330. 51	. 005	3. 2		370. 24	. 006	4. 7
Total variable cost		8, 951. 12	. 126	86. 1		7, 163. 94	. 124	90. 4
Depreciation [4]		994. 74	. 014	9. 6		368. 21	. 006	4. 6
Interest [5]		453. 23	. 006	4. 3		392. 61	. 007	5. 0
Total fixed cost		1, 447. 97	. 020	13. 9		760. 82	. 013	9. 6
Total costs [6]		10, 399. 09	. 146	100. 0		7, 924. 76	. 137	100. 0
Manure credit [7]		166. 97	. 002			135. 19	. 003	
Net cost [6]		10, 232. 12	. 144			7, 789. 57	. 134	

[1] See table 31 and figure 10 for changes in prices since 1929.
[2] Chore labor, average price of 10 cents per hour. Quantities per year carried to nearest whole hour.
[3] Feed, see p. 32.
[4] Depreciation, difference in value for the opening and closing inventories.
[5] Interest at 6 percent.
[6] Not including shelter, taxes, insurance, or wages for operator.
[7] Manure credit, based on 90 cents per ton and on the estimated tons saved.

The estimated values of feeds per unit on the plantations were as follows: Oats, 61 cents and corn, $1.07 per bushel; commercial feeds, $46.86 per ton; various hays, from $14.36 to $23.14 per ton; green feed, $7.14 per ton; and pastures, from $1 to $1.81 per month, depending on kind.

Depreciation for mules is the difference in values for the opening and closing inventories. Interest was figured at 6 percent. The credit for manure was obtained by estimating the number of tons saved per plantation, and valuing it at 90 cents per ton.

The largest difference in cost per hour of mule work was between the group of mule plantations and general-purpose tractor plantations, amounting to 2.1 cents per hour of mule work or 21 cents per 10-hour day. Most of this difference was in feed cost. Costs of depreciation and interest on the hour basis were practically the same on all groups of plantations except the mixed-tractor plantations, when they were about 50 percent higher than on any other group.

AGE OF MULES

Work mules of all ages on the plantations studied numbered 6,659 head at the close of the year covered by the survey. Ages were obtained on 3,491 head and a frequency distribution of such ages appears in table 21. Ages for the 3,168 head not individually classified, that is, those mules listed only in age groups, averaged 9.8 years for 974 head on mule plantations; 9.9 years for 941 head on general-purpose tractor plantations; 10.6 years for 474 head on ordinary-tractor plantations; and 10.2 years for 779 head on mixed-tractor plantations. The average age of the 3,168 head was 10.0 years, as compared with the 8.9 years for the 3,491 head shown in table 21. The average age of the 6,659 head was 9.5 years.

TABLE 21.—*Classification of mules according to age, on plantations of different power types, 1929*

Age of mules (years)	Mules of specified age used on—				Total	Age of mules (years)	Mules of specified age used on—				Total
	Mule plantations	General-purpose tractor plantations	Mixed (ordinary and general-purpose) tractor plantations	Ordinary-tractor plantations			Mule plantations	General-purpose tractor plantations	Mixed (ordinary and general-purpose) tractor plantations	Ordinary-tractor plantations	
	Number	*Number*	*Number*	*Number*	*Number*		*Number*	*Number*	*Number*	*Number*	*Number*
4	42	4	------	------	46	14	40	7	36	------	83
5	41	51	33	15	140	15	17	40	1	2	60
6	77	161	43	54	335	16	2	40	------	4	46
7	110	154	135	22	421	17	4	1	------	------	5
8	392	311	66	54	823	18	7	1	4	3	15
9	103	335	68	65	571	19 and over	23	3	15	7	48
10	295	203	23	50	571						
11	21	53	28	------	102		*Years*	*Years*	*Years*	*Years*	*Years*
12	107	90	------	14	211	Average age	9.1	8.9	8.7	8.7	8.9
13	12	2	------	------	14						

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The most common age for work mules in the Delta was from 6 to 10 years. Of the 3,491 head listed in table 21, 2,907, or approximately 83 percent, were 10 years old or under. On the plantations on which mules are the exclusive source of power, only well-broken, mature animals are generally worked.

NUMBER, WEIGHT, AND VALUE OF WORK STOCK

As shown in table 22, the average weights and values of mules in the various power-type groups of plantations varied little. On the average, the mules that worked on the plantations in the ordinary-tractor group were the lightest, while those that worked on the mixed-tractor plantations were the heaviest. The average difference in weight between the mules of these two extreme groups approximated 100 pounds per head. Quality rather than age or weight was probably the one factor most influential in fixing valuation, for table 21 indicates that there was little difference in the average age of mules on the several types of plantations.

TABLE 22.—*Number, weight, and value of work stock on plantations, classified by power type, 1929*

Power type of plantation	Plantations surveyed	Crop land per plantation	Mules			Mares (horses)			Geldings (horses)			All work stock		
			Total	Average weight	Average value	Total	Average weight	Average value	Total	Average weight	Average value	Average per plantation	Average weight	Average value
	No.	*Acres*	*No.*	*Lb.*	*Dol.*	*No.*	*Lb.*	*Dol.*	*No.*	*Lb.*	*Dol.*	*No.*	*Lb.*	*Dol.*
General-purpose tractor	65	857	2,638	1,036	121.89	16	975	122.66	14	1,147	145.71	41	1,036	122.02
Mule	63	665	2,311	1,023	107.75	9	1,003	83.89	13	1,042	107.27	37	1,023	107.66
Mixed (ordinary and general-purpose) tractor	19	1,331	1,244	1,074	113.80	6	950	97.08	9	1,138	151.94	66	1,074	114.00
Ordinary-tractor	14	1,056	745	977	122.53	4	900	42.50	2	1,000	76.25	54	977	121.98
Total or average	161	855	6,938	1,032	115.80	35	969	99.14	38	1,101	130.38	44	1,032	115.80

FEEDS CONSUMED BY WORK STOCK

Table 23 gives the average quantities of feeds used per head per year. Aside from the group of ordinary-tractor plantations, no great difference was shown in the total number of pounds of concentrates consumed per head annually. Work stock on mule plantations were the heaviest users of grain and grain-substitute feeds, since they did the most work (table 10). There was considerable uniformity among the different types of plantations in the quantities of corn and oats fed per head. In calculating the poundage of these grains fed, corn was converted on a shelled basis of 56 pounds per bushel, and 32 pounds of oats to the bushel was accepted as the standard. The quantities of commercial feeding stuffs consumed were about the same per head on mule and general-purpose tractor plantations, but varied widely on the other two types. The average quantity of commercial feed used per head was obtained from a total reported use of 935.3 tons of mixed feed, of which 168.9 tons were known as "sweet" feed,[2] and 4.7 tons were cottonseed meal.

[2] Commercial feed products containing varying quantities of low-grade molasses.

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TABLE 23.—*Average quantities of feeds consumed per head per year by work stock on plantations, classified by power type, 1929*

Power type of plantation	Work stock	Concentrates				Roughage					Pasture			
		Corn	Oats	Commercial feeds	Total	Legume hay	Mixed hay	Nonleguminous hay	Succulence	Total	Grass	Grain	Other	Total
	No.	*Bu.*	*Bu.*	*Lb.*	*Lb.*	*Tons*	*Ton*	*Ton*	*Ton*	*Lb.*	*Days*	*Days*	*Days*	*Days*
General-purpose tractor	2,668	40.2	16.0	147.4	2,911	2.22	0.28	0.32	0.18	6,000	27.0	4.2	0.9	32.1
Mule	2,333	40.6	18.7	166.6	3,039	1.97	.10	.41	.08	5,120	42.0	4.5	5.4	51.9
Mixed (ordinary and general-purpose) tractor	1,259	41.1	10.6	310.9	2,952	2.51	.02	.58	.10	6,420	14.4	0	0	14.4
Ordinary-tractor	751	40.8	7.2	75.4	2,591	1.96	.79	.06	.44	6,500	11.4	1.2	1.8	14.4
Total or average	7,011	40.6	15.0	175.4	2,927	2.16	.23	.37	.16	5,836	28.1	3.2	2.3	33.6

Large quantities of leguminous roughage were used on all plantations. Hays of this kind constituted over two thirds of the roughage. Alfalfa and soybean hays were particularly popular. The total tonnage of different legume hays were as follows: Alfalfa, 6,209.9 tons; soybeans, 4,445.5 tons; cowpeas, 456.2 tons; lespedeza, 295.3 tons. The total quantity of mixed hays reported used on all plantations by all work stock was 1,371.3 tons. The total tonnages of nonleguminous roughages used were: Sorghum, 875.9 tons; prairie and grass hays, 1,120.6 tons; grain hay, 138.4 tons; straw, 12.6 tons; cottonseed hulls, 7.0 tons; and corn fodder (cornstalks with ears attached), 2.0 tons.

Sorghum, sagrain, and corn cut green were the succulent feeds reported as used for Delta work stock. The total quantities of these feeds used were: Sorghum, 685.2 tons; sagrain, 219.0 tons; green corn, 1,028 bushels.

Grass pasture was the only kind utilized to any great extent and this only on mule and general-purpose tractor plantations. There is an interesting relation between the average quantity of roughage consumed per head per year and the amount of pasture utilized by work stock. On the mule plantations where the use of pasturage was greatest the quantity of roughage fed was smallest. On ordinary-tractor and mixed-tractor plantations, on the other hand, the largest quantities of roughage and the smallest amounts of pasture were used for work stock. General-purpose tractor plantations were intermediate between the above-mentioned extremes in roughage and pasture utilization by work stock.

Another significant item is the quantity of corn fed to work stock as compared with oats. Corn is a highly carbonaceous grain feed and its extensive use probably accounts for the heavy feeding of legume hays with it, as a means of obtaining nutritive balance in the ration. The predominance of corn in the concentrate ration is accounted for mainly by the fact that it is more suited as a crop to local soil and climatic conditions.

Taking into consideration the amount of annual work done per head and the systems and methods of work-stock feeding and management followed, it does not appear that Delta planters were feeding excessively. But by using different feeding and management practices, thus reducing feed and chore-labor costs, they could have saved considerable sums. A common failing was the too limited use of pasture. As shown in table 23, the mules and horses worked on the plantations

studied were on pasture an average of only 33½ days annually. The average number of hours work per head per year varied from 1,006 to 1,122 (table 11). With this amount of work, it was evident that idle work stock, or those at intermittent work, spent too much time in the "dry lot" on costly concentrates and roughage. Feed expense and that for chore labor for such animals could have been greatly reduced and their health could have been improved by maintaining them on pasture. Rotation pastures help to maintain soil fertility and to reduce fertilizer bills.

Feeding idle work stock working rations was very common and kept feed consumption at high levels. Big savings in feed can be made by properly regulating the quantity of feed. Full-time work for work stock averaged as much as 100 days on only a few plantations, and full rations were required for only that time. The quantities of concentrates and hay ordinarily required for mules and horses at heavy work vary from 1 to 1¼ pounds of each daily for each 100 pounds of body weight. For part-time work the concentrates should be cut from one third to one half that required for heavy work, and the animals should be maintained principally on pasture and dry roughage. During periods of complete idleness, good pasture should be relied upon as the principal feed when available, and it should be supplemented with grain and dry roughage only when necessary.

Further economies lie in the increased production and use of home-grown feeds. Rotation pastures should be used in place of high-priced hay for idle work stock and those at infrequent work. Information concerning pastures for certain localities can be obtained from the agricultural experiment stations of Mississippi and Arkansas.

COST OF DRAWBAR WORK ON COTTON PRODUCED PRINCIPALLY WITH TRACTOR POWER

The average annual cost of operating a tractor on the 24 plantations, producing cotton principally with tractor power, selected from the 65 general-purpose tractor plantations (p. 11), was $550. The cost per hour was 59 cents, or 7 cents lower than the average for all general-purpose tractors shown in table 17. The average age of the 46 tractors on these 24 plantations was 2 years. Repairs averaged $40 per tractor. Total variable costs, including fuel, lubricants, repairs, and repair labor, averaged 36 cents per hour and the fixed costs of depreciation and interest averaged 23 cents per hour.

On these 24 plantations, the cost of tractor-drawbar work on the cotton grown almost exclusively with mechanical power averaged $3.59 and of mule work 53 cents per acre of cotton, or a total power cost of $4.12 (table 24). Land preparation and fitting constituted approximately 42 percent of the total power cost, planting 5 percent, cultivating 51 percent, and miscellaneous operations 2 percent. The cost of man labor per acre averaged $1.33 for tractor operators and 43 cents for teamsters, or a total man-labor cost of $1.76. The combined cost of man labor and mechanical and animal power amounted to $5.88 per acre of cotton.

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TABLE 24.—*Average cost per plantation of drawbar work on cotton produced principally with tractor power, 24 plantations, 1929* [1]

Operation	Cost per plantation [2]		Cost per acre [3]		
	Tractor work	Mule work	Tractor work	Mule work	Total
	Dollars	*Dollars*	*Dollars*	*Dollar*	*Dollars*
Flat breaking	39.14	0.72	0.20		0.20
Disking, flat, and beds	119.13		.60		.60
Harrowing	27.65	1.32	.14	0.01	.15
Bedding	108.07	9.99	.55	.05	.60
Fertilizing	17.67	6.83	.08	.04	.12
Planting	36.79	6.25	.19	.03	.22
Cultivating	359.85	59.79	1.82	.30	2.12
Miscellaneous	2.38	19.15	.01	.10	.11
Total	710.68	104.05	3.59	.53	4.12

[1] See table 31 and figure 10 for changes in costs since 1929.
[2] For work on the cotton produced principally with tractor power.
[3] Per acre of cotton, about 100 acres per tractor.

The outstanding tractor performance on the 24 plantations was that of two general-purpose tractors on a 1,200-acre plantation. Eight hundred acres were in cotton, and the tractors handled 300 acres of cotton and 100 acres of soybean hay. The tractors were the first ever used on the plantation. One had been used one season and the other, two. The 1929 repair bill totaled $150. The tractor equipment included two 2-disk plows, two 6-foot tandem disk harrows, one 4-row planter, two 4-row cultivators, one tractor mower, and a power duster, representing a total investment of $1,400 for equipment, and $3,480 for tractors and equipment. A 1½-ton truck with trailer and bed was bought in 1929 for $1,650. The total investment in power machinery amounted to $5,130.

The crop work of the two tractors totaled 2,134 hours on cotton and 510 hours on soybeans, making a total of 2,644 hours of drawbar crop work. In addition to crop work the two tractors did 230 hours of ditching and grading, and some orchard work. Including all drawbar and belt work the two tractors averaged 1,530 hours of work per year.

Tractor power cost $1,947, or 64 cents per tractor per hour of operation. Gasoline that cost 19 cents per gallon was used exclusively. Another relatively high operating charge was for depreciation, which totaled $520 per year. Depreciation and repair charges could probably have been kept down by better supervision.

COST OF USING TRACTORS ON DIFFERENT OPERATIONS

Tractors pulling 4-row implements covered from 26 to 30 acres per 10-hour day and were operated at a cost of approximately 20 cents per acre (table 25 and fig. 9). These costs include depreciation, interest, fuel, lubricants, repairs, and repair and chore labor. They do not include labor for operating the tractor. The tractor power cost of pulling 2-row cultivators, drills, 2-row planters, bedders, harrows, and disks amounted to from 28 to 40 cents per acre. Power for plowing with 2-disk plows cost $1.19 per acre.

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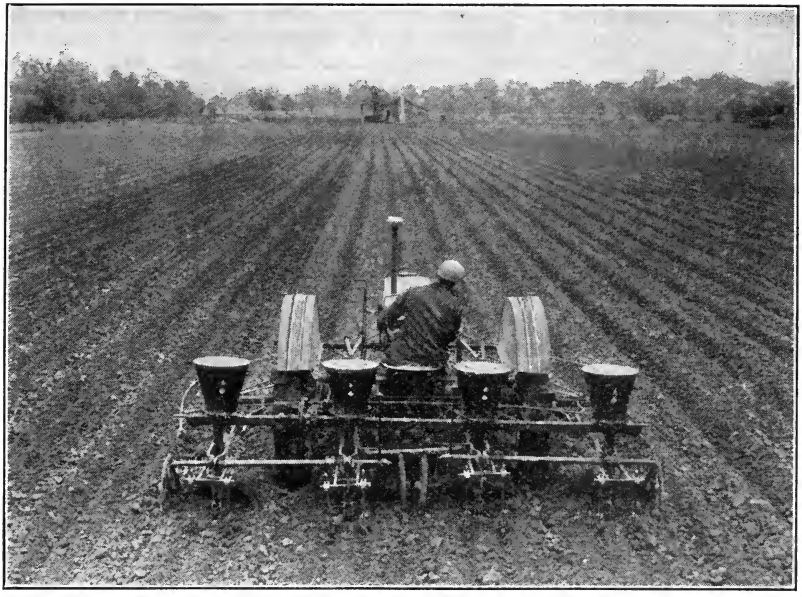

FIGURE 9.—A general-purpose tractor and a 4-row buster-planter. One or two men with such an outfit can plant about 30 acres of cotton in a 10-hour day.

TABLE 25.—*Average cost of tractor work, specified operations on 24 plantations that had cotton on which tractors were the principal kind of power, 1929* [1]

Operation	Tractor work per plantation		Operating cost		Operation	Tractor work per plantation		Operating cost	
			Per year	Per acre				Per year	Per acre
	Acres [2]	*Hours*	*Dollars*	*Dollars*		*Acres* [2]	*Hours*	*Dollars*	*Dollar*
Flat breaking, 2-disk plow	77	142	91. 93	1. 19	Planting:				0. 39
Disking, flat, and beds	573	318	191. 91	. 33	2-row	38	27	14. 73	
Harrowing	216	72	40. 66	. 19	4-row	161	54	31. 53	. 20
Bedding	238	161	94. 99	. 40	Drilling	29	14	8. 31	. 29
Fertilizing, 4-row	80	30	17. 55	. 22	Cultivating:				
					2-row	423	232	120. 54	. 28
					4-row	1, 346	454	268. 41	. 20

[1] See table 31 and figure 10 for changes in costs since 1929.
[2] Computed as acreage on which the operation was performed multiplied by the "times over."

COST OF USING MOTOR TRUCKS

COST PER YEAR AND PER HOUR

The variable costs of using motor trucks included fuel, oil, grease, license, repair parts (including tires and batteries) and labor for making repairs and servicing. Fixed costs included depreciation and interest.

One hundred and one motor trucks were owned on 87 plantations. The size of the trucks ranged from one half to 4 tons. Sizes ranging

from 1 to 1½ tons were most common, however, as the load capacity of 90 of the trucks was within that range.

The average cost of using the trailer-type motor trucks was computed separately from the rest. The average annual cost of operating the 18 trailer-type trucks, exclusive of custom hauling, was $525 as compared with $359.28 for the 83 trucks without trailers.[3] The trucks with trailers were used, on the average, 76 days in the year. Variable costs, which are closely associated with the amount of work done, averaged $239.36, or 45.6 percent, of the average total cost for that group. In comparison, the trucks without trailers were used a smaller number of days (64), and variable costs were a higher percentage of the total. The variable costs of the latter group averaged $194.26, or 54 percent, of the total. Fuel, oil, and grease were the principal items of variable cost for the first group; they averaged $104.02, or 19.9 percent, of the total cost. For the trucks operated without trailers, the largest item of variable cost was that for repairs and expert labor. The average cost for the group was $90.80, or 25.3 percent, of the total as compared with $102.61 per truck, or 19.5 percent of the total cost of operating the trailer-type trucks. The average cost of fuel, oil, and grease for the group of trucks not operated with trailers was $73.99, or 20.5 percent, of the total.

Depreciation was based on the estimated years of service after purchase by the present owner. One trailer-type truck and 18 trucks without trailers were second-hand. The average purchase price for the trailer-type trucks was $1,083 and that of the trucks without trailers was $672. Interest was computed at 6 percent of one-half of the purchase price.

On the hour basis, the total cost of using trailer-type trucks was 69 cents per hour as compared with 53 cents per hour for trucks without trailers.

The average expense for hauling with hired trucks on the 87 farms on which trucks were owned amounted to $6.74. The cost per hour for hauling with hired trucks was less than that with owned trucks.

The amount of custom work done with trucks was small. The 18 trailer-type trucks were used 3 days, on the average, and those without trailers were used only 2 days.

COST OF POWER ON PLANTATIONS ON WHICH TRACTORS WERE USED

The total cost of work done by tractors, mules, motor trucks, gas engines, and electric motors in 1929 on plantations on which tractors were owned averaged $8,318 per plantation. Hired power constituted 1.2 percent of the total. Table 26 shows power costs on the tractor plantations classified by type of tractor used.

[3] These costs do not include taxes, and no allowance was made for trade-in value in calculating depreciation.

TABLE 26.—*Average annual cost per plantation of using different types of power on tractor plantations, 1929* [1]

GENERAL-PURPOSE TRACTOR PLANTATIONS

Size group (cotton acres)	Plantations surveyed	Average cotton acreage	Cost of using owned power					Cost of hiring motor trucks	Total cost of using power				
			Tractor		Motor truck	Mules	Miscellaneous		Owned	Hired [2]	Owned and hired	Per acre in cotton	Per acre of all crops
			Drawbar work	Belt work									
	No.	*Acres*	*Dol.*	*Dol.*	*Dol.*	*Dol.*	*Dol.*	*Dol.*	*Dol.*	*Dol.*	*Dol.*	*Dol.*	*Dol.*
150 to 399	19	265	534.18	17.92	255.82	2,208.70	11.91	113.91	3,028.53	119.64	3,148.17	11.88	8.63
400 to 799	27	543	558.27	33.40	196.65	5,232.45	8.48	139.93	6,029.25	141.78	6,171.03	11.36	8.24
800 and over	19	1,184	1,012.16	71.70	384.12	10,935.87	41.18	98.74	12,445.03	98.74	12,543.77	10.59	8.35
Total or average	65	649	683.90	40.07	268.75	6,015.74	19.04	120.28	7,027.50	122.72	7,150.22	11.02	8.34
MIXED (ORDINARY AND GENERAL-PURPOSE) TRACTOR PLANTATIONS													
Total or average	19	933	1,215.26	94.60	395.62	10,232.12	66.69	32.83	12,004.29	35.19	12,039.48	12.90	9.05
ORDINARY-TRACTOR PLANTATIONS													
Total or average	14	792	398.20	88.29	321.40	7,789.57	30.14	59.85	8,627.60	59.85	8,687.45	10.97	8.23

[1] See table 31 and figure 10 for changes in costs since 1929.
[2] Includes mule work hired on general-purpose tractor plantations, and drawbar tractor work hired on mixed-tractor plantations.

On all plantations on which tractors were owned, the cost of mule power averaged 85 percent of the total cost of power, tractor power 10 percent, motor-truck power 5 percent, and miscellaneous power less than 0.5 percent. These same relationships held closely on plantations having general-purpose tractors whether they were the only type used or were used in combination with other types. On plantations with ordinary tractors, however, where tractors were used less, mule power constituted 90 percent and tractor power 6 percent of the total cost.

In comparing total power costs the size of plantation, as indicated in table 26 by acreage in cotton, should be considered. General-purpose tractor plantations with the smallest acreage in cotton had the lowest total power cost. Power costs were highest per acre on the mixed-tractor plantations on which there was a heavier investment in tractor equipment and a lower utilization of mule work.

There was a sufficient number of general-purpose tractor plantations to warrant a classification by size of business. Table 26 shows these plantations arranged by size into three groups which will be referred to as small, medium, and large plantations. There was roughly an increase in size of 100 percent in one group over the next smaller. Total power costs increased 96 and 103 percent, respectively, with size of plantation, or almost in exact proportion to increase in acres of cotton. The large plantations averaged 2 tractors per plantation compared with 1.2 on small and 1.3 on medium plantations. Eighteen trucks were owned on the large plantations, 12 on the medium, and 16 on the small plantations.

On the medium plantations, tractor and truck costs were influenced by the number owned. There was a greater amount of hired motor trucking in this group, however, than in the other groups. Miscellaneous power was used on all three size groups with higher costs on the larger ones. This, however, constituted less than 0.5 percent of the total power cost.

For each acre of cotton, tractor costs were $2.08 on the small plantations, $1.09 on medium, and 91 cents on the large plantations. Of these amounts about 6 cents for each group was for belt work. The decrease in tractor costs as size of plantation increased was accompanied by an increase in mule costs. The mule costs were $8.33, $9.63, and $9.24, respectively. Truck costs per acre of cotton for both owned and hired trucks were $1.40 on small plantations, of which 96 cents was for owned trucks; 62 cents on medium plantations, of which 36 cents was for owned trucks; and 41 cents for large plantations of which 32 cents was for owned trucks. Total costs per acre were smallest on the largest plantations where the largest percentage of the total work was done with mule power.

INVESTMENT IN POWER MACHINERY ON TRACTOR PLANTATIONS

Power machinery on tractor plantations may be classified for convenience, as tractors and tractor equipment, motor trucks, and miscellaneous. Tractors and tractor equipment constituted 75 percent of the total investment in power machinery, trucks 20 percent, and other power machinery 5 percent. On individual plantations the total investment ranged from less than $1,000 to over $11,000. Table 27 shows the number of plantations having power machinery of specified values. On 46 percent of all tractor plantations the investment in power machinery was under $2,500; on 40 percent it ranged from $2,500 to less than $5,000, and on 14 percent it was over $5,000.

TABLE 27.—*Classification of tractor plantations according to type of tractor owned and average investment* [1] *in power machinery, 1929*

Investment group (dollars)	General-purpose tractor plantations	Mixed (ordinary and general-purpose) tractor plantations	Ordinary-tractor plantations	Investment group (dollars)	General-purpose tractor plantations	Mixed (ordinary and general-purpose) tractor plantations	Ordinary-tractor plantations
	Number	*Number*	*Number*		*Number*	*Number*	*Number*
500 to 999			1	4,000 to 4,499	5		
1,000 to 1,499	12		4	4,500 to 4,999	2	1	
1,500 to 1,999	14		3	5,000 to 5,499	4	2	
2,000 to 2,499	7		4	5,500 to 5,999	1		
2,500 to 2,999	10	5		6,000 and over	3	4	
3,000 to 3,499	7	4					
3,500 to 3,999		3	2	Total	65	19	14

[1] Purchase price.

Table 28 shows the average investment in tractors, tractor equipment, motor trucks, and miscellaneous power equipment. For all plantations the average investment in all power machinery was $4.24 per acre of cotton.

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TABLE 28.—*Average investment* [1] *in power machinery on tractor plantations, classified by type of tractor owned, 1929*

Power type of plantation	Tractors	Motor trucks	Tractor machinery		Other machinery	Total	Investment per acre of cotton
			Drawbar	Belt			
	Dollars	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*
General-purpose tractor	1,403	580	681	92	121	2,877	4.43
Mixed (ordinary and general-purpose) tractor	2,282	759	1,013	177	306	4,537	4.86
Ordinary-tractor	946	574	240	104	121	1,985	2.51

[1] Purchase price.

COST OF POWER ON PLANTATIONS ON WHICH MULES WERE USED

Power costs on plantations on which mules were used are shown in table 29. They do not include charges for labor used in operating the owned-power units. They do include, however, such charges for hired power.

TABLE 29.—*Average annual cost per plantation of using different types of power, on mule plantations, 1929* [1]

Size group (cotton acres)	Plantations surveyed	Average cotton acreage	Cost of using owned power			Cost of using hired power					Total			Cost per acre of—	
			Mules	Motor truck	Miscellaneous	Mules	Motor truck	Tractor		Miscellaneous	Owned power	Hired power	Owned and hired	Cotton [2]	All crops
								Drawbar work	Belt work						
	No.	*Acres*	*Dol.*	*Dol.*	*Dol.*	*Dol.*	*Dol.*	*Dol.*	*Dol.*	*Dol.*	*Dol.*	*Dol.*	*Dol.*	*Dol.*	*Dol.*
150 to 399	31	263	2,662.56	125.21	0	20.32	47.73	14.10	11.55	0	2,787.77	93.70	2,881.47	10.96	8.26
400 to 799	23	551	4,842.26	214.76	8.79	4.78	34.28	8.03	0	2.61	5,065.81	49.70	5,115.51	9.28	7.29
800 and over	9	1,267	14,709.96	105.76	0	3.89	236.22	4.64	23.22	4.64	14,815.72	272.61	15,088.33	11.91	9.12
Total or average	63	512	5,179.39	155.13	3.21	12.30	69.75	10.53	9.00	1.62	5,337.73	103.20	5,440.93	10.63	8.18

[1] See table 31 and figure 10 for changes in costs since 1929.
[2] Total cost divided by cotton acreage only.

That power is a major item of expense is evidenced by the fact that its average cost for the mule plantations was $8.18 per acre of crops, and $10.63 per acre of cotton (all costs borne by the cotton crop). Of the total, the cost of work done by mules owned on the plantations amounted to over 95 percent, leaving only about 5 percent for all other classes of power, both owned and hired. Feed cost is the major item of this expense; it amounted to 78.8 percent of the total (table 20). The difference among plantation groups in the total cost per mule was due principally to differences in feed costs. Depreciation was the next most important item. The acreage per mule also apparently affected the cost of power per acre.

On the 63 mule plantations, 27 motor trucks were owned; 11 were in the first size group, 13 in the second, and 3 in the third.

COMPARISON OF POWER COSTS ON PLANTATIONS ON WHICH TRACTORS AND MULES WERE USED

From references to tables 26 and 29 it is seen that the average total cost of all power in 1929 on general-purpose tractor plantations amounted to $11.02 per acre of cotton or $8.34 per acre of all crops; on mixed-tractor plantations, $12.90 and $9.05; on ordinary tractor plantations, $10.97 and $8.23; and on mule plantations $10.63 and $8.18, respectively. These costs do not include charges for labor used in operating the owned-power units. They do include, however, such charges for hired power.

Due to the relative newness of the general-purpose tractor on cotton plantations in 1929, changes in the power organization were constantly being made. With further experience, adjustments may be made that will lower power costs on plantations using this type of tractor. Table 30 shows that the number of crop acres per mule was greater for all tractor plantations than for the mule plantations. The smallest general-purpose tractor plantations had 7 more crop-acres per mule than did the same size mule plantations, while the 2 larger size groups had 2 and 3 more crop-acres per mule, respectively.

Table 30 shows the cost of all drawbar operations on crops done with mules alone or with mules and tractors. The average cost for all drawbar work on crops per crop-acre in 1929 was 19 cents lower on the general-purpose tractor plantations than on the mule plantations and 82 cents lower than on the mixed-tractor plantations.

TABLE 30.—*Average cost per acre in crops and per acre in cotton for drawbar work in growing and harvesting crops, 1929* [1]

Size group (cotton acres)	Plantations surveyed	Average cotton acreage	Crop acreage per plantation	Mules per plantation	Crop acreage per mule	Cost of drawbar work					
						Per acre in crops			Per acre in cotton		
						Mules	Tractor	Total	Mules	Tractor	Total
	Number	*Acres*	*Acres*	*Number*	*Acres*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*
GENERAL-PURPOSE TRACTOR PLANTATIONS											
150 to 399	19	265	365	15	24	5.03	1.39	6.42	6.92	1.92	8.84
400 to 799	27	543	749	35	21	5.90	.67	6.57	8.13	.92	9.05
800 and over	19	1,184	1,503	75	20	5.81	.59	6.40	7.37	.75	8.12
Total or average	65	649	857	41	21	5.75	.72	6.47	7.59	.95	8.54
MULE PLANTATIONS											
150 to 399	31	263	349	20	17	6.46	.04	6.50	8.58	.05	8.63
400 to 799	23	551	702	37	19	5.77	.01	5.78	7.35	.01	7.36
800 and over	9	1,267	1,654	96	17	7.74	-------	7.74	10.10	-------	10.10
Total or average	63	512	665	37	18	6.64	.02	6.66	8.62	.02	8.64
MIXED (ORDINARY AND GENERAL-PURPOSE) TRACTOR PLANTATIONS											
Total or average	19	933	1,331	66	20	6.55	.74	7.29	9.34	1.06	10.40
ORDINARY-TRACTOR PLANTATIONS											
Total or average	14	792	1,056	54	20	6.38	.29	6.67	8.50	.38	8.88

[1] See table 31 and figure 10 for changes in costs since 1929.

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Since cotton occupied 75 percent of the total crop land for all plantations, the cost of drawbar power per acre of cotton is a more important consideration than the cost per acre of all crops. On this basis the drawbar-power cost on the general-purpose tractor plantations averaged 10 cents per acre less than on the mule plantations and $1.86 less than the mixed-tractor plantations

Among the different power type groups of plantations there was a range in the average cost of drawbar power per acre in all crops of 82 cents, and per acre in cotton of $1.86. The lowest average cost of drawbar work was on the general-purpose tractor plantations (table 30). The range in the average total cost of all power, including that for hauling and for stationary work (tables 26 and 29) was somewhat greater, amounting to 87 cents per acre in all crops and $2.27 per acre in cotton, and the lowest average cost of all power was on the mule plantations. On the various size groups of general-purpose tractor plantations and mule plantations, the average costs of drawbar power and total power per acre in crops and in cotton were not influenced alone by the type of power but by other factors such as number of crop acres per mule or per tractor.

For example, in the size group of smallest plantations the cost of drawbar power per crop acre was 8 cents lower on the general-purpose tractor plantations than on the mule plantations; but the cost per acre in cotton was 21 cents lower on the mule plantations. In the second group, the mule plantations showed a lower cost in each instance than did the general-purpose tractor plantations, partly because of a larger number of crop acres per mule. For the largest size group, costs on the mule plantations were higher in both instances. These cost figures do not include a charge for the labor used in operating owned power units.

CHANGES IN POWER COSTS SINCE 1929

During the 4 depression years immediately following 1929, the year covered in this study, the prices of many items of cost in the use of farm power decreased markedly (fig. 10 and table 31). The greatest decrease occurred in prices of mule feeds and in wages of farm labor. The result is that the cost of animal power decreased much more than the cost of tractor power.

TABLE 31.—*Index numbers of cost of mule work and tractor work, and of prices of specified items of such costs, 1929–33*

[1929=100]

Item	1929				1930			
	Jan.	Apr.	July	Oct.	Jan.	Apr.	July	Oct.
Mules [1]	96	107	102	100	98	100	90	73
Corn [1]	94	106	107	94	88	94	94	96
Oats [1]	99	101	97	100	101	104	84	93
Hay [1]	96	101	103	96	101	107	100	105
Labor [1]	95	100	101	104	98	98	94	81
Tractor [2]	100	100	100	100	100	95	95	95
Tractor fuel [3]	100	94	100	100	94	94	94	82
Tractor oil [4]	100	100	100	100	101	101	100	100
Mule work	96	103	104	96	96	101	96	97
Tractor work	100	98	100	100	98	96	95	98

See footnotes at end of table.

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TABLE 31.—*Index numbers of cost of mule work and tractor work, and of prices of specified items of such costs, 1929–33*—Continued

Item	1931				1932				1933			
	Jan.	Apr.	July	Oct.	Jan.	Apr.	July	Oct.	Jan.	Apr.	July	Oct.
Mules [1]	68	80	76	63	62	77	68	66	62	77	84	80
Corn [1]	85	86	79	35	35	37	35	33	28	39	70	57
Oats [1]	90	81	55	45	46	48	40	40	42	45	75	72
Hay [1]	103	105	79	54	55	55	49	50	44	51	60	61
Labor [1]	68	63	63	56	54	49	43	43	41	41	44	51
Tractor [2]	95	95	95	87	87	87	87	87	87	87	87	87
Tractor fuel [3]	82	76	71	76	82	82	100	82	88	82	88	100
Tractor oil [4]	100	99	98	96	95	90	89	85	89	85	84	88
Mule work	91	92	76	48	48	50	44	44	40	48	65	61
Tractor work	88	85	83	82	84	83	90	82	85	82	84	90

[1] Computed from farm prices in Mississippi and Arkansas, U. S. Department of Agriculture Crops and Markets.
[2] Computed from index numbers for United States, Wholesale Prices for 2-plow tractors, United States Department of Labor.
[3] Gasoline, kerosene, and fuel oil, weighted according to quantities used. Computed from prices at Jackson, Miss., compiled by National Petroleum News.
[4] Computed from data furnished by the Bureau of Agricultural Economics on prices paid by farmers for cylinder oil, United States averages. Reported for December, March, June, and September.

Although some items of expense such as tractor fuel, mule values, and farm wages, began to decline in the summer of 1930, the cost of keeping a mule and the cost of operating a tractor were about as high in 1930 as in 1929. By October 1931, however, mule-power costs had dropped to about 50 percent of the costs in 1929, whereas tractor-power costs had dropped to about 80 percent of the costs in 1929. Mule-power costs remained at about the October 1931 level, or slightly lower, until the spring of 1933, and then advanced to 65 percent of the costs in 1929, but fell off again in October 1933 to 60 percent of the costs in 1929. Tractor-power costs remained at between 80 and 90 percent of the 1929 costs from the summer of 1931 until the fall of 1933.

These changes in power costs are based upon changes in the prices of the cost factors. For mules, the items of corn, oats, hay, chore labor, and depreciation, which comprised more than 90 percent of the cost of keeping mules in 1929, were used in estimating changes in mule-power costs. For tractor costs, the costs of fuel, lubricants, chore labor, repairs and expert labor, and depreciation, which comprised more than 90 percent of the operating costs in 1929, were used in estimating changes in costs.

SUMMARY

Tractors have been used in the Delta since 1915, but they did not become common on plantations until about 1927, when the general-purpose type was introduced.

Mechanization in the South as compared with other agricultural regions may be expected to lag until a mechanical cotton picker is perfected.

Of the 161 plantations surveyed, 65 were operated with general-purpose tractors and mules, 63 with mules alone, 19 with tractors of mixed types and mules, and 14 with ordinary tractors and mules.

Mixed-tractor plantations averaging 1,806 acres were the largest and mule plantations with 941 acres were the smallest.

For all plantations crop land averaged 74 percent of the total area and cotton occupied 75 percent of the cropped land.

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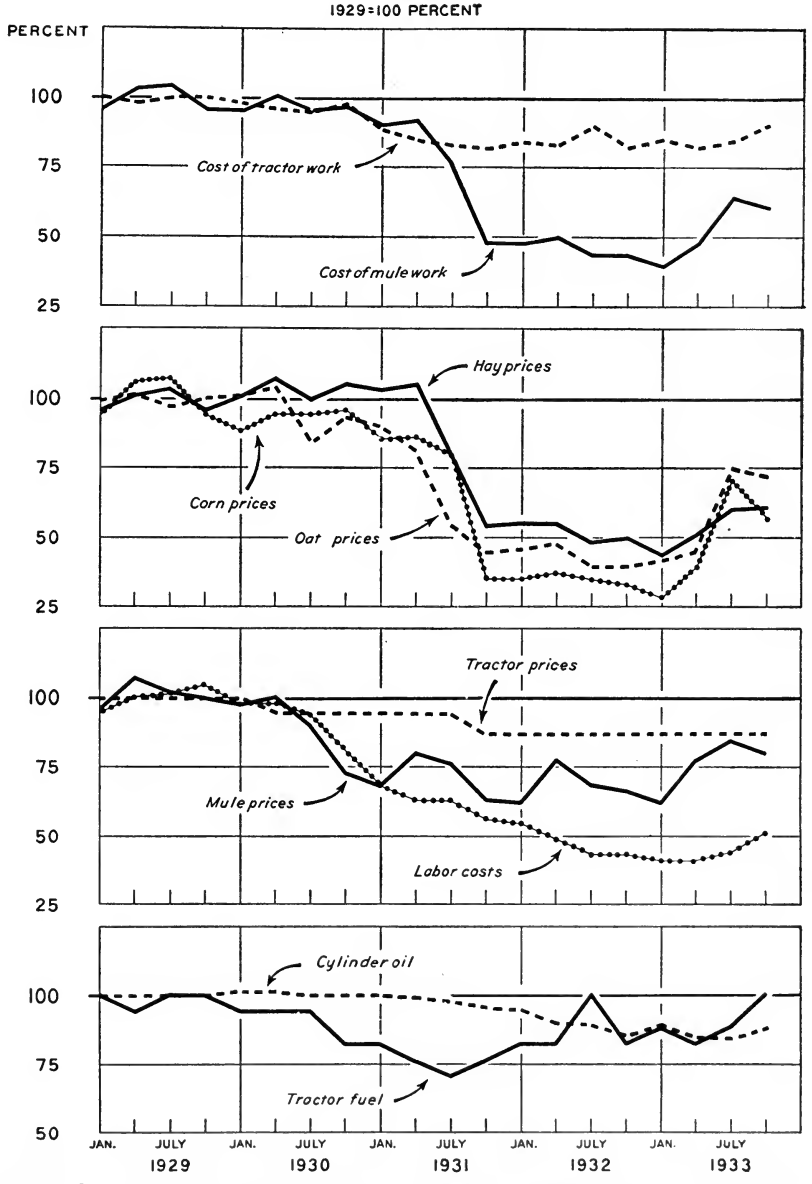

FIGURE 10.—INDEX NUMBERS OF COST OF MULE WORK AND TRACTOR WORK, AND OF PRICES OF IMPORTANT COST ITEMS, 1929-33.

The cost of using mules declined more following 1929 than did the cost of operating tractors. 1929=100 percent.

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On general-purpose tractor plantations there were from 1 to 6 tractors per plantation, on mixed-tractor plantations from 1 to 5 tractors, and on ordinary-tractor plantations there was but 1 tractor per plantation with the single exception of one plantation on which there were 2.

The number of mules per plantation ranged from 2 to 198. The average number on mixed-tractor plantations was 66, on ordinary-tractor plantations 54, on general-purpose tractor plantations 41, and on mule plantations 37.

Size of plantation is a factor in the ownership of motor trucks, the larger ones owning the most trucks.

Mechanical power other than that of tractors and motor trucks for plantation work was but little used.

On 24 of the 65 plantations using general-purpose tractors about 100 acres of cotton, the equivalent of that handled by six tenants, were produced principally with tractor power for each tractor owned.

On all general-purpose tractor plantations there was an average of 1,094 hours of tractor work per year, on mixed-tractor plantations 1,853 hours, and on ordinary-tractor plantations 470 hours.

Tractors averaged 431 hours or 43.1 days of work per tractor annually.

Forty percent of all tractors were used less than 500 hours and 17 percent were used 1,100 hours or more per year.

Tractors were used on plantations more for disking than for any other operation.

On 60 percent of the general-purpose tractor and 58 percent of the mixed-tractor plantations, tractors were used for cultivating.

Running hay balers was the principal belt work done by tractors.

On general-purpose tractor and mixed-tractor plantations, 17 percent of the total drawbar work on crops was done with tractors, while on the ordinary-tractor plantations, only 5 percent of the drawbar work on crops was done with tractors.

Mules on mule plantations did an average of one hundred twelve 10-hour days work per year, on both ordinary- and mixed-tractor plantations 108 days, and on general-purpose tractor plantations 100 days.

Over 50 percent of all mule work was for bedding and cultivating.

Of the 161 planters, 87 owned 101 motor trucks that supplemented mules for hauling. The remaining 74 used mules alone or mules and hired trucks.

The plantations having trucks were an average distance of 8.2 miles from their preferred markets and the rest were 4.3 miles.

An average of 2,219 miles of hauling per year was done with mules by planters not owning motor trucks. An average of 3,871 miles of hauling with motor trucks and 1,375 miles with mules was done by planters owning motor trucks.

Mule hauling, including time for loading, unloading, and waiting, as at the cotton gin, required 2.3 hours per mile; motor-truck hauling required only 11 minutes per mile.

Man labor varied from 117.5 hours per acre in cotton with general-purpose tractors to 190 hours with mules.

On 24 plantations, the drawbar requirements per acre of cotton produced principally with tractor power amounted to 6 tractor-hours and 4.1 mule-hours.

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The average annual cost of using tractors, exclusive of the operator's labor, was 70 cents per hour, based on an average of 705 hours of operation. Power by general-purpose tractors cost 66 cents per hour based on 733 hours; by mixed-type tractors, 71 cents based on 733 hours; and by ordinary tractors $1.04 based on 439 hours of use annually.

Fuel and lubricants constituted 41 percent, and depreciation constituted 36 percent, of the total tractor-operating cost.

Repairs fluctuated with the age of the machines and ranged from 6 cents per hour for general-purpose tractors to 19 cents for ordinary tractors.

The average age of ordinary 2-plow tractors was 4.8 years, 3-plow tractors 3.5 years, and general-purpose tractors 1.8 years.

The annual cost of using tractor-drawn implements ranged from $22 for middle busters to $64 for four-row cultivators.

The cost per hour of mule work was lowest, 12.5 cents, on mule plantations where mules worked 112 days, and it was the highest, 14.6 cents, on general-purpose tractor plantations where they worked 100 days.

The cost of feed was 78.8 percent of the total cost of using mules on mule plantations.

The average age of the 6,659 mules was 9.5 years, and their average value was $115.80.

Mules consumed during the year an average of 2,927 pounds of concentrates, 5,836 pounds of roughage, and were on pasture 33.6 days per head.

The 101 motor trucks ranged from one half to 4 tons in capacity. Eighteen had trailers.

Trucks with trailers were used 76 days and those without trailers 64 days.

The average yearly cost of motor-truck operation was 69 cents per hour for trucks with trailers and 53 cents for those without trailers.

The average cost of power for all tractor plantations was $11.48 for each acre in cotton.

Investment in power machinery for all tractor plantations averaged $4.24 per acre in cotton.

The average cost of power on mule plantations amounted to $10.63 per acre in cotton.

The cost of drawbar work on crops with mules and tractors ranged from $8.54 per acre in cotton on general-purpose tractor plantations to $10.40 on mixed-tractor plantations. On mule plantations, the cost was $8.64 per acre in cotton. Such costs per crop acre ranged from $6.47 on general-purpose tractor plantations to $7.29 on mixed-tractor plantations, and were $6.66 on mule plantations.

Cost of mule work and tractor power in 1930 was about the same as in 1929.

In October 1931 the cost of mule work had dropped to about 50 percent and tractor power to about 80 percent of 1929 costs. By 1933 the cost of tractor power stood at about 90 percent of the 1929 level and that of mule work at about 60 percent.

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GROWTH AND SURVIVAL OF DECIDUOUS TREES IN SHELTER-BELT EXPERIMENTS AT MANDAN, N. DAK., 1915–34

By Ernest J. George

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INTRODUCTION

A series of investigations was commenced in 1914 by the United States Department of Agriculture at the Northern Great Plains Field Station, Mandan, N. Dak., to determine the possibilities of growing trees which would provide shelter to farm buildings, orchards, and gardens on the northern Great Plains from damaging winds and drifting snow. The practice of planting trees for this purpose had been carried on by many of the early settlers before that time with only very minor success. Lack of experience in land preparation and planting methods for trees and the use of species and practices recommended for more favorable parts of the country were responsible for many of the failures. A resulting impression prevailed that trees could not be grown under the adverse conditions found in the section.

The investigations carried on by the Mandan station consist of (1) experimental plantings on the station proper for the purpose of testing the hardiness of native and introduced tree species and to determine the spacing distances and methods necessary to grow successfully the species found hardy, and (2) the cooperative demon-

[1] The following men under W. A. Peterson, superintendent from 1913–17, and J. M. Stephens, superintendent since 1918, have been responsible for the care of the shelter-belt experiments and for collecting data on them; Max Pfaender, assistant horticulturist, 1913–15; Robert Wilson, associate arboriculturist, 1916 and 1920–28; F. E. Cobb, assistant arboriculturist, 1917–19; and the writer since 1929. The writer's connection with the shelter-belt experiments began in 1922.

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stration shelter-belt project, whereby trees are furnished to farmers for planting shelter belts under specified conditions on approved planting sites. This bulletin deals only with the shelter-belt combination experiments with broadleaf trees begun in 1915, which include only a part of the investigations with trees conducted at the Mandan station. Narrowleaf or coniferous species of trees are included in other experiments in the investigations outlined above. The shelter-belt combinations were set out as being representative of typical shelter belts which it was expected would be established on farms in connection with the cooperative demonstration shelter-belt project.

The Mandan station is located near the central-eastern boundary of the northern Great Plains in the United States, which may be said to include that portion of North Dakota and South Dakota lying west of the one hundredth meridian and that part of Montana and Wyoming lying east of the foothills of the Rocky Mountains.

REVIEW OF THE LITERATURE

Several bulletins and circulars have been published on shelter belts and windbreaks for the prairie regions, but few contain data on height growth and survival of the species commonly used in these plantings. Ross (*11*)[2] gives average yearly heights for a number of deciduous and coniferous species growing in plantations on the Indian Head Forestry Station, Indian Head, Saskatchewan, Canada. Cheyney (*4*) gives average heights of a number of deciduous and coniferous species at 4, 5, and 6 years after planting, which were planted in shelter belts in the prairie section of Minnesota. Harrington and Morgan (*6*) give survival and rate of growth figures for several deciduous species planted in a shelter belt at the Northern Montana Branch Station. Jensen and Harrington (*7*) give survival and height figures for deciduous species in a series of methods of spacing, pruning, and cultivation tests at the Judith Basin Branch Station, Moccasin, Mont. Wilson and Cobb (*13*) give average height figures by States for a number of species planted in cooperative shelter belts throughout the northern Great Plains. Bates (*3*) and Cheyney (*4*) have made studies of the influence of shelter belts in reducing wind velocity, checking evaporation, and the benefit of shelter belts to farm crops. Other writers, Bates (*2*), Edmondson (*5*), Johnson and Cobb (*8*), Ross (*10*), Trenk (*12*), and Yeager (*14*), give considerable information on trees and methods recommended for farm shelter belts in the prairie and Plains regions.

CLIMATIC CONDITIONS

Climatic conditions on the Mandan station are fairly representative of the general climatic conditions throughout the northern Great Plains.

The monthly, seasonal, and annual precipitation data at the Mandan station for the 20-year period 1915–34 are presented in table 1. The annual precipitation of 8.13 inches in 1934 was 6.86 inches below normal and 2.18 inches below that of the next lowest annual precipitation of 10.31 inches, which occurred in 1917. Approximately 69 percent of the mean annual precipitation falls during the months of April to August, inclusive, when the soil is in suitable condition for absorbing and retaining water.

[2] Italic numbers in parentheses refer to Literature Cited, p. 48.

Ten of the twenty years show an annual precipitation of below the average for the period. Weather records (*9*) for the 59-year period 1875–1933 show the years 1917, 1918, 1919, 1920, and 1921 to be the 5 driest consecutive years on record. The average annual precipitation at Bismarck was 16.67 inches for the 59-year period and 12.62 inches for the 5-year period.

Moisture conditions in 1915 were decidedly favorable for establishing the stand of trees set out that year and for storing moisture in the soil prepared for later plantings. The trees set out in 1916 received approximately the normal precipitation, but the trees set out in 1917 received a precipitation of 4.68 inches below the 20-year average. Three years of subnormal precipitation followed.

The evaporation from a free water surface during the 20-year period, months of April to September, inclusive, ranged from 28.616 to 40.746 inches and averaged 34.474 inches. The highest monthly evaporation is in July and the lowest is in April. Eight of the twenty years show a seasonal evaporation above the average for the period.

TABLE 1.—*Monthly, seasonal, and annual precipitation at the Northern Great Plains Field Station, Mandan, N. Dak., for the 20-year period 1915–34*

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Seasonal, Apr. to Aug.	Annual
	In.	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*
1915	0.07	Trace	0.30	1.11	4.98	6.32	6.48	0.63	1.84	1.85	0.34	0.14	19.52	24.06
1916	.28	.09	1.88	.93	1.69	2.25	3.55	2.04	.92	.27	.07	1.10	10.46	15.07
1917	.28	.19	.35	1.87	.35	2.56	1.58	.89	1.97	.05	.03	.19	7.25	10.31
1918	.20	.11	.45	2.61	2.45	.68	2.47	2.03	.63	.27	.45	1.02	10.24	13.37
1919	.08	.80	.83	1.72	3.95	1.12	.85	1.22	.49	.98	1.19	.25	8.86	13.48
1920	.52	.20	1.21	.58	1.72	1.85	2.68	1.81	1.29	.25	.37	.21	8.64	12.69
1921	.18	.09	.79	2.59	3.05	.82	3.38	.25	1.58	1.39	.87	.24	10.09	15.23
1922	.28	1.55	.52	.66	2.05	3.43	3.17	.32	2.31	.64	1.60	.82	9.63	17.35
1923	.36	.38	.16	1.85	1.18	1.94	4.12	1.15	2.31	.54	.28	.14	10.24	14.41
1924	.03	.25	.28	1.68	.41	5.56	2.07	2.35	1.34	1.94	.06	.28	12.07	16.25
1925	.28	.03	.44	.94	1.18	7.34	.33	1.31	.99	.69	.15	.38	11.10	14.06
1926	.71	.22	.04	.13	2.41	1.20	2.19	1.31	2.38	.18	.30	.44	7.24	11.51
1927	.18	.14	1.17	1.37	6.65	2.00	2.37	3.16	.49	.44	1.56	.77	15.55	20.30
1928	.20	.07	.23	.99	.55	6.32	4.94	2.24	.89	.19	.06	.17	15.04	16.85
1929	.80	.31	1.47	1.75	2.68	.99	1.20	.81	1.56	1.81	.14	.70	7.43	14.22
1930	.19	1.68	Trace	1.71	2.23	1.50	2.40	2.00	2.56	1.85	1.13	.13	9.84	17.38
1931	.05	.44	1.62	.43	2.14	1.65	4.32	1.01	3.11	1.46	.47	.74	9.55	17.44
1932	.44	.19	1.00	1.99	3.48	3.33	1.90	.70	.24	2.12	.19	.18	11.40	15.76
1933	1.23	.34	1.02	.86	1.83	2.18	1.80	.41	.27	.55	.90	.52	7.08	11.91
1934	.06	.05	.58	.63	.17	3.78	1.10	.25	.47	.73	.17	.14	5.93	8.13
Average	.32	.36	.72	1.32	2.26	2.84	2.64	1.29	1.38	.91	.52	.43	10.36	14.99

The mean annual temperature for the 20-year period was 41° F. July, with an average mean temperature of 70°, was the warmest month, and January with an average mean temperature of 9° was the coldest. The highest temperature recorded was 110° in July and the lowest was −43° in January. The 20-year average mean monthly temperature was below freezing in January, February, March, November, and December. Subzero temperatures were recorded during the same months and also in October. Temperatures of 100° or greater were recorded during the months of June, July, August, and September.

The 20-year average wind velocity, measured 2 feet above the ground surface with a Robinson four-cup anemometer, was 6 miles per hour. April has the highest average velocity, 7.3 miles per hour, and July the lowest, 4.8 miles per hour.

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FACTORS AFFECTING TREE GROWTH

The climatic data show that trees must be able to withstand great extremes of temperature, periods of limited moisture, high winds, and a high evaporation rate if they are to survive and make successful growth. The high summer and low winter temperatures subject trees to an extreme range of 153° F. Alternate periods of freezing and thawing with sudden drops from high to low temperatures frequently result in killing a part of a tree if not the whole of it. The limited average annual precipitation, together with the high average seasonal evaporation and the frequently long periods in which the soil is in a frozen condition, necessitate that tree species withstand very limited conditions of water supply.

Among other factors of considerable importance are high winds, which with the dry atmosphere cause rapid losses of water from the soil, from the leaves in summer, and from twigs and branches in winter. Hailstorms during the summer months frequently damage trees and in some instances entirely destroy young plantings. Drifting snow which settles in the trees oftentimes breaks down side branches and entire trees. Ross (*11*) cites instances in the Prairie Provinces of Canada where the tops of entire plantings of cottonwood and Manitoba maple have been completely broken down by drifting snow, the result being stunted and bushy trees. Trees with tender bark frequently sun-scald on the southwest side, resulting in serious injury to the trunks.

Damage in varying degrees is done locally by rodents, such as by rabbits and mice girdling trees, and by insects of leaf-eating, sap-sucking, and boring habits. A tree planting in this section is subject to any or all of the above factors, and only those species can survive that are able to adjust themselves to the prevailing conditions.

The tolerance to shade and the habit of root development are factors of considerable importance in determining the ability of a tree species to survive under severe climatic conditions. An intolerant species improperly placed in the tree planting may quickly become overtopped by a faster-growing species in an adjacent row, resulting in a stunted growth and finally suppressed and dying trees, unless they are released by thinning operations. The removal of dominant trees from a shelter belt for this purpose results in opening up the crown cover. This tends to encourage grass and weed undergrowth that seriously competes with the trees for available moisture.

The habit of root development has an important influence on the length of life of tree species in regions of limited rainfall. Shallow-rooted species, such as willow and poplar, which send their roots along the surface of the soil, are comparatively short-lived, owing to the feeding area of the roots being in the surface layers which are subject to constant drying by winds and a high evaporation rate. Species developing more or less of a taproot system, such as ash and elm, survive periods of extreme drought when the more shallow-rooted species kill out entirely.

EXPERIMENTAL METHODS AND CONDITIONS

The shelter-belt combination experiments under discussion consist of a series of 22 separate belts or combinations of trees planted during the years 1915, 1916, and 1917 and grown strictly under dry-land con-

ditions. The belts range from 2 to 22 rows in width, each row being 100 feet long running north and south. A cultivated roadway of 24 feet is left on all sides of each belt. Combinations 1 to 7 were set out in 1915, combinations 8 to 17 in 1916, and combinations 18 to 22 in 1917.

The belts are composed of what was considered at the time of planting to be the most promising broadleaf species for shelter belts. The purpose of these belts was to obtain data on spacing distances; height growth, survival, adaptability, and congeniality of species; the most suitable trees for outside rows; and the optimum width of shelter belts. The general arrangement of species and the spacing distances were patterned after similar plantings made by the Canadian Department of the Interior at Indian Head, Saskatchewan. The Canadian Government had been carrying on the planting of farm shelter belts in the Prairie Provinces of Canada since 1901 with very gratifying results.

The tree stock comprising the 22 combinations was planted on land that had been broken from sod during 1913 and 1914. This land had been broken years before but had reverted to sod. All combinations were planted on land that had been fallowed for one or more years previous to planting.

The combinations have been kept free of any weed growth by horse cultivation and hand-hoeing during the summer months. Corrective pruning has not been practiced on any species in this series. The trees were allowed to branch naturally, which resulted in multiple-stemmed trees in many of the species. The reason for allowing natural branching was the assumption that the more branches or stems developed per tree, the more effective would the planting become in breaking the force of wind and in holding drifting snow. The value of this in practice is questionable, as more wind and snow breakage have been observed in multiple-stemmed trees than in trees pruned to one main trunk.

The spacing distances used in this series of tests were 2 by 8 feet for 2 combinations, 4 by 4 feet for 10 combinations, 4 by 8 feet for 9 combinations, and 6 by 12 feet for 1 combination.

The common and scientific names of the 18 species or kinds of trees used in planting the 22 combinations are as follows:

Common name	Scientific name
American plum	*Prunus americana*
Birch	*Betula* sp.
Boxelder	*Acer negundo*
Buffaloberry	*Lepargyrea argentea*
Carolina poplar	*Populus eugenei*
Chinese elm	*Ulmus pumila*
Chokecherry	*Prunus virginiana*
Diamond willow	*Salix mackenzieana*
Gray birch	*Betula populifolia*
Green ash	*Fraxinus pennsylvanica lanceolata*
Laurel willow	*Salix pentandra*
Northwest poplar	*Populus* sp.
Norway poplar	Do.
Poplar	Do.
Red willow	[3]
Russian golden willow	[3]
Sharpleaf willow	*Salix acutifolia*
Siberian pea-tree	*Caragana arborescens*

[3] Horticultural varieties. Standardized Plant Names (*1*) recommends the use of common names only.

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The year of planting, spacing distance, number of rows, and arrangement of species for each of the 22 combinations are given in table 2. The spacing distance gives (1) the distance between trees in the row, and (2) the distance between rows.

TABLE 2.—*Year of planting, spacing, number of rows, and arrangement of species of trees in 22 shelter-belt combinations grown at the Northern Great Plains Field Station*

Combination no.	Year planted	Spacing distance	Rows	Arrangement of trees (from east to west)
		Feet	*Number*	
1	1915	4 by 4	12	Gray birch, green ash, gray birch, green ash, gray birch, green ash, gray birch, green ash, gray birch, green ash, gray birch, green ash.
2	1915	4 by 4	16	Chokecherry, chokecherry, boxelder, boxelder, green ash, green ash, Carolina poplar, Carolina poplar, boxelder, boxelder, laurel willow, laurel willow, Russian golden willow, Russian golden willow. chokecherry, chokecherry.
3	1915	4 by 4	22	American plum, American plum, boxelder, green ash, boxelder, green ash, boxelder, green ash, boxelder, green ash, Carolina poplar, Russian golden willow, Carolina poplar, Russian golden willow, Carolina poplar, Russian golden willow, Carolina poplar, Russian golden willow, diamond willow, diamond willow, American plum, American plum.
4	1915	4 by 4	20	Siberian pea-tree, Siberian pea-tree, green ash, green ash, green ash, green ash, Carolina poplar, Carolina poplar, Carolina poplar, Carolina poplar, boxelder, boxelder, boxelder, boxelder, laurel willow, laurel willow, laurel willow, laurel willow, Siberian pea-tree, Siberian pea-tree.
5	1915	2 by 8	16	Siberian pea-tree, Siberian pea-tree, boxelder, boxelder, green ash, green ash, Carolina poplar, Carolina poplar, boxelder, boxelder, laurel willow, laurel willow, Russian golden willow, Russian golden willow, Siberian pea-tree, Siberian pea-tree.
6	1915	2 by 8	20	Siberian pea-tree, Siberian pea-tree, green ash, boxelder, green ash, boxelder, green ash, boxelder, green ash, boxelder, Carolina poplar, laurel willow, Carolina poplar, laurel willow, Carolina poplar, laurel willow, Carolina poplar, laurel willow, Siberian pea-tree, Siberian pea-tree.
7	1915	4 by 4	8	Green ash, Russian golden willow, green ash, Russian golden willow, green ash, Russian golden willow, green ash, Russian golden willow.
8	1916	4 by 8	2	Siberian pea-tree, laurel willow.
9	1916	4 by 8	3	Siberian pea-tree, Carolina poplar, laurel willow.
10	1916	4 by 8	4	Siberian pea-tree, Norway poplar, boxelder, laurel willow.
11	1916	4 by 8	5	Russian golden willow, boxelder, poplar species, boxelder, laurel willow.
12	1916	4 by 8	6	Russian golden willow, poplar species, boxelder, poplar species, boxelder, laurel willow.
13	1916	4 by 8	8	Siberian pea-tree, laurel willow, poplar species, Russian golden willow, poplar species, Russian golden willow, poplar species, Russian golden willow.
14	1916	4 by 8	10	Laurel willow, laurel willow, poplar species, boxelder, poplar species, boxelder, poplar species, boxelder, poplar species, Russian golden willow.
15	1916	4 by 4	18	Laurel willow, laurel willow, boxelder, boxelder, green ash, green ash, boxelder, boxelder, poplar species, poplar species, boxelder, boxelder, poplar species, poplar species, boxelder, boxelder, laurel willow, laurel willow.
16	1916	[1] 4 by 4	9	Boxelder, Russian golden willow, boxelder, poplar species, boxelder, green ash, boxelder, laurel willow, boxelder.
17	1916	[2] 4 by 4	4	Siberian pea-tree, boxelder, green ash, laurel willow.
18	1917	6 by 12	6	Boxelder, green ash, Chinese elm, Northwest poplar, birch species, sharpleaf willow.
19	1917	4 by 4	10	Buffaloberry, sharpleaf willow, boxelder, green ash, Chinese elm, Northwest poplar, birch species, green ash, boxelder, sharpleaf willow.
20	1917	4 by 8	5	Buffaloberry, boxelder, Chinese elm, birch species, sharpleaf willow.

[1] Trees in rows 1 and 9 are 2 feet apart.

[2] Trees in rows 1 and 4 are 2 feet apart.

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TABLE 2.—*Year of planting, spacing, number of rows, and arrangement of species of trees in 22 shelter-belt combinations grown at the Northern Great Plains Field Station*—Continued

Combination no.	Year planted	Spacing distance	Rows	Arrangement of trees (from east to west)
		Feet	*Number*	
21	1917	4 by 4	20	Buffaloberry, sharpleaf willow, red willow, boxelder, birch species, boxelder, green ash, boxelder, Northwest poplar, Chinese elm, boxelder, green ash, birch species, Northwest poplar, boxelder, green ash, birch species, red willow, sharpleaf willow, birch species.
22	1917	[3] 4 by 8	10	Buffaloberry, sharpleaf willow, birch species, Northwest poplar, Chinese elm, birch species, green ash, boxelder, red willow, birch species.

[3] Trees in rows 1 and 10 are 2 feet apart.

PLANTING STOCK

The stock used for planting the shelter-belt combinations was grown from seed or cuttings on the Mandan station or purchased as seedlings from commercial sources. A brief description of the origin, natural range on the northern Great Plains, and characteristics of the different species follows:

American plum.—The plum was grown from seed collected near Mandan. It is native along bottoms and coulees throughout the section. It has a low, fairly dense growth and is suitable for outside rows in a shelter belt. Ordinarily it suckers profusely from the base and will spread rapidly over cultivated land. Periodic crops of fruit of varying quality are produced. A few trees of this species have been planted in many shelter belts.

Birch sp.—The birch was grown from seed collected in the Killdeer Mountains of North Dakota. Its range in this section is confined chiefly to the Killdeer Mountains. It is of comparatively low growth, slender branches, and light foliage. Very few trees of this species have been planted in shelter belts.

Boxelder.—The boxelder was grown from seed collected near Mandan. It ranges throughout the section along bottoms, hillsides, and coulees. It is a rapid grower in early life, branches considerably, and quickly forms a dense shade. It rarely develops tree form except under favorable moisture conditions. It has the objectionable features of suckering profusely at the base and of harboring several species of undesirable insects. It has been extensively used in shelter belts throughout the Great Plains, particularly in the early years.

Buffaloberry.—The buffaloberry was grown from seed collected near Mandan. It ranges throughout the entire section along bottoms, coulees, and hillsides. It has a fairly low, dense form of growth and is suitable for outside rows in a shelter belt. Crops of fruit which serve useful household purposes are produced most years. Under natural conditions, it spreads by root suckers and quickly covers small areas. Seedlings are difficult to transplant, and the trees become subject to fungus attack and wind breakage after a few years of growth. Many shelter belts and farmyards contain a few trees of this species.

Carolina poplar.—The Carolina poplar was propagated from cuttings taken from trees growing on the station. The trees were previously purchased from a commercial nursery. Commercial nurseries introduced this species as a horticultural variety from its native range in the central or eastern United States. It grows rapidly to a considerable height under favorable moisture conditions and has a conical crown with fairly dense foliage. Early shelter belts contained large numbers of trees of this species.

Chinese elm.—The seedlings of the Chinese elm were obtained from the United States Plant Introduction Garden at Chico, Calif. It was introduced by the United States Department of Agriculture from China in 1908. It grows rapidly under normal dry-land conditions to a considerable height with spreading branches which have fairly dense foliage. The wood is extremely brittle, and "splits" in crotches commence early in life. For this and other reasons it is desirable to place the species in the interior of the shelter belt, where it will be afforded some wind protection by species on either side. It has become very popular in recent years, and many shelter belts are now planted to this species in pure stand.

Chokecherry.—The chokecherry was purchased as seedlings from a commercial nursery in North Dakota. It ranges throughout the entire section along bottoms, coulees, and hillsides. It is of low growth, except in moist situations, where it may attain a height of 20 feet. It suckers profusely from the base, quickly spreading over an area of cultivated land unless kept in check. Considerable quantities of fruit are produced most years, which are eagerly sought for household purposes. It has become a popular shelter-belt tree in recent years and is being planted in increasing quantities. Birds carry the seed of this species for considerable distances, and it is frequently found forming an understory in old tree plantings.

Diamond willow.—The diamond willow was grown from cuttings taken from trees along the Heart River near Mandan. It ranges throughout the entire section along river and creek bottoms. It seldom attains very much height, owing to the older wood continually dying out and new shoot growth taking its place. Very few trees of this species have been used in shelter belts. The wood makes very durable fence posts and is eagerly sought by landowners for this purpose.

Gray birch.—The seedlings of gray birch were purchased from a commercial nursery. It has a limited range in the section, being found chiefly in the Killdeer Mountains of North Dakota and in some sections of Montana, where it grows to a considerable height with light foliage. Very few trees of this species have been used in shelter belts.

Green ash.—The green ash was grown from seed collected in the vicinity of Mandan. It ranges throughout the entire section along bottoms and up coulees to the open prairie. Its long life and good form of growth under native conditions make it a desirable tree for mixture with other species in shelter belts. It is very subject, however, to borer infestation in southern North Dakota and practically all of South Dakota. Many native trees and those planted in shelter belts in the infested area have been killed by the infestation in recent years.

Laurel willow.—The stock of laurel willow was grown from cuttings taken from trees growing on the station. These trees were previously purchased from a commercial nursery. The species develops a bushy form of growth and dense foliage under favorable moisture conditions. Very few trees have been planted in shelter belts, except along the extreme eastern border of the section.

Northwest poplar.—The stock of Northwest poplar was grown from cuttings taken from trees previously purchased from a commercial nursery. The species is generally accepted as being a natural hybrid native to the north-central part of North Dakota. It is a rapid grower and attains considerable height under favorable moisture conditions. It has a desirable form of growth, but it is subject to canker and borer injury at an early age. It was quite popular for a number of years and was extensively planted in shelter belts in mixture with other species or in pure stand.

Norway poplar.—The stock of Norway poplar was grown from cuttings taken from trees previously purchased from a commercial nursery. It is an introduced horticultural variety and has growth habits and characteristics somewhat similar to those of Carolina poplar. This species was extensively used in shelter belts during the early years.

Poplar sp.—The stock of poplar was grown from cuttings taken from trees previously purchased from a commercial nursery. It is an introduced horticultural variety and develops a more spreading crown than the Norway and Carolina poplar. It grows rapidly to a considerable height under favorable moisture conditions. Very few trees of this species have been planted in shelter belts.

Red willow.—The stock of red willow was grown from cuttings taken from trees previously purchased from a commercial nursery. It develops a very weak form of growth and light foliage and is considered a horticultural variety. Very few trees have been planted in shelter belts.

Russian golden willow.—The stock of Russian golden willow was grown from cuttings taken from trees previously purchased from a commercial nursery. It develops considerable height under favorable moisture conditions and usually has several stems per tree. The species was originally introduced from Russia and was extensively planted in shelter belts during the early years.

Sharpleaf willow.—The stock of sharpleaf willow was grown from cuttings taken from trees originally obtained from Indian Head Forestry Station, Saskatchewan, Canada. It is found native in the western part of the section, occurring in the foothills of the Rocky Mountains. It develops several stems per tree and grows to a considerable height under favorable moisture conditions. It is prob-

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ably the best willow for planting under conditions of limited moisture, but it has been used only in limited quantities.

Siberian pea-tree.—The Siberian pea-tree was grown from seed obtained from Indian Head Forestry Station, Saskatchewan, Canada. It was introduced from Siberia a number of years ago and has been found to be remarkably drought-resistant. It develops a low, bushy, dense form of growth and is very suitable for outside rows on the windward side of a shelter belt. It has been extensively planted for many years, but has lost some of its popularity in recent years owing to the susceptibility of complete defoliation the entire growing season by blister beetles and grasshoppers.

INSECTS AND OTHER ENEMY PESTS

The 18 species used in the 22 shelter-belt combination tests have been subjected to various insect and fungus attacks. Siberian pea-tree has been badly defoliated by blister beetles most years. Practically all tree species were defoliated by these insects in 1932. Box-elder and green ash were completely defoliated in 1928 and 1929 by canker worms, and occasional defoliation of these two species has been caused by the *Cecropia* moth. Buffaloberry has been injured to

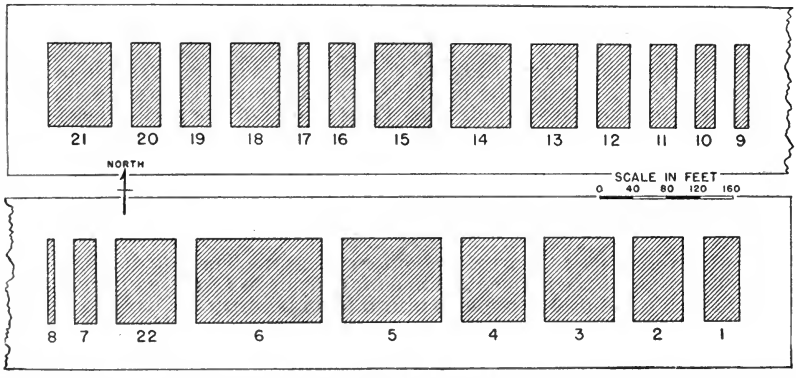

FIGURE 1.—Planting plan of 22 shelter-belt combinations planted in 1915, 1916, and 1917 at the Northern Great Plains Field Station, Mandan, N. Dak.

some extent by fungus infection, resulting in rotting of the wood and eventual breaking off of the infected portion. Poplar species are more or less subject to canker injury and infestation by borers. Spraying to control leaf-eating insects has been practiced in several years. No attempt has been made to control the other insects or fungi.

LOCATION AND SOIL OF SHELTER-BELT COMBINATIONS

The shelter-belt combinations are situated along the extreme northern boundary of the station land. They are located on comparatively high, fairly level tableland. Immediately north of the station boundary the land slopes northward to the valley of the Heart River. Differences in topography throughout the area of the plantings are small, except the sites of combination 21, which slopes sharply to the south and west, and combinations 10, 11, and 12, which are located in a small depression. Water drains to this depression during periods of heavy rainfall and has an important influence on the

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growth and survival of willow species. A scale diagram of the 22 shelter-belt combinations is shown in figure 1.

The soil being light and deep is considered favorable to the growth of trees. Corn, small grains, grasses, and vegetable crops do well on it. Corn on this soil averaged 26.3 bushels per acre from 1915 to 1934. It is a typical dry-farming soil in that there is no water table. The normal annual cycle is an accumulation of available water during the dormant period and extending into the spring and its exhaustion by growing vegetation during the summer.

The following brief description and chemical analysis of the soil were furnished by C. F. Marbut, in charge of the Division of Soil Survey, Bureau of Chemistry and Soils, United States Department of Agriculture.[4]

The soil on the Mandan tract varies considerably, especially in texture. That on the plateau above the terrace on which the field-station buildings stand is a loam, the sand constituent being fine to very fine. On the experimental plats the soil is sandy loam. The experimental plats around the station buildings are located on a bench, consisting of a terrace, but the texture of the substratum is not light enough to affect the moisture relations in the soil horizons.

The normal mature soil of the region has a profile in which the alluvial horizon universally characteristic of the subsoil in humid regions is absent. The subsoil has about the same texture as the soil except in those spots where the texture of the former horizon is determined by geological factors rather than the processes of soil development. This latter condition would apply only to the soils on the terraces and not those on the uplands. [The subsoil of the shelter belts is uniformly a silty, fine sand to a depth of at least 10 feet.]

The color of the soils on the uplands, as well as that of the medium and heavier soils of the experiment plats, is best described as a strong dark brown, almost black. The dark-colored horizon in the virgin soil is about 8 inches thick, underlain by a brown horizon extending to a depth of about 2 feet. Below this lies the usual zone of accumulated carbonate of lime.

This soil lies on or near the western border of the true black earth of the United States. The color of the surface soil is dark enough to be placed in that group, but the 16-inch to 18-inch horizon of brown loam between the dark-colored surface horizon and the carbonate zone does not permit its correlation as a typical member of that group. It is also somewhat too dark to be placed in the zone of chestnut-colored soils. So far as existing knowledge of its characteristics will permit any decision as to its place in the general scheme of dry-land soils, it must be considered as a nontypical chernozem. In the scheme of classification used by the Bureau of Soils it is a member of the Williams series.

The composition of a sample taken from the plateau, locally known as the Custer Flats, 2 miles south of the station buildings, is shown in table 4. The figures in this table show the total quantities of the constituents present.

The chemical analysis confirms the statement made above that the "good clay subsoil," universally present in the mature soils of the humid part of the United States and recognized by the farmers, is absent here. The analysis shows no concentration of either iron oxide or alumina in the subsurface, whereas the composition of the mature soils in the humid region invariably shows more or less concentration of this kind.

The content of lime, potash, and nitrogen is all good to high, and that of phosphoric acid is high.

[4] STEPHENS, J. M., WILSON, R., BAIRD, W. P., SARVIS, J. T., THYSELL, J. C., KILLAND, T. K., and BRINSMADE, J. C., JR. REPORT OF THE NORTHERN GREAT PLAINS FIELD STATION FOR THE 10-YEAR PERIOD, 1913–1922, INCLUSIVE. U. S. Dept. Agr. Bull. 1301, 80 pp., illus. 1925. See pp. 5–6.

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TABLE 3.—*Chemical analysis of soil collected at the Northern Great Plains Field Station*

[Table 4, U. S. Dept. Agr. Bull. 1301]

Analysis for—		Depth		
		0 to 7 inches	7 to 24 inches	24 to 36 inches
Silica, SiO_2	percent	70.31	70.74	60.71
Titanium dioxide, TiO_2	do	.57	.66	.55
Ferric oxide, Fe_2O_3	do	3.47	4.03	3.91
Alumina, Al_2O_3	do	12.47	13.18	12.97
Manganese oxide, MnO	do	.087	.079	.055
Lime, CaO	do	1.12	1.08	6.69
Magnesia, MgO	do	.76	1.53	2.69
Potash, K_2O	do	2.52	2.34	2.28
Soda, Na_2O	do	1.05	1.10	.91
Phosphorus pentoxide, P_2O_5	do	.17	.17	.17
Sulphur trioxide, SO_3	do	.11	.09	.09
Ignition loss [1]	do	7.64	4.89	9.16
Nitrogen, N	do	.244	.11	.065
Carbon dioxide, CO_2 (from carbonates)	do			5.65
Water, H_2O at 110° F	do	2.33	2.30	2.50

[1] Nitrogen, carbon dioxide, and water are included in ignition loss and should not be added again in computing the totals, which approximate 100 percent and are within the limits of error of the analyses.

The physical composition of the soil to the depth of 4 feet is shown in the analysis of soil samples collected from an adjoining field (table 4).

TABLE 4.—*Physical analysis of soil samples collected at the Northern Great Plains Field Station in 1915* [1]

Foot section	Designation of materials (percent)						
	Fine gravel 2 to 1 mm	Coarse sand 1 to 0.5 mm	Medium sand 0.5 to 0.25 mm	Fine sand 0.25 to 0.1 mm	Very fine sand 0.1 to 0.05 mm	Silt 0.05 to 0.005 mm	Clay 0.005 to 0 mm
First	0.3	0.9	1.8	31.9	26.1	30.4	8.3
Second	.2	.9	2.1	36.1	25.4	27.5	7.5
Third	.7	.9	2.3	41.5	29.5	17.7	7.0
Fourth	1.7	2.3	2.8	35.3	28.0	22.0	7.6

[1] Analysis furnished by the Bureau of Soils, U. S. Department of Agriculture, in 1916.

METHOD OF COLLECTING DATA

Only a very small amount of data was collected in 1915 and 1916 from the combinations set out during those years. From 1917 to 1922, inclusive, the average heights of the different rows were determined by estimation. Stand data were determined by actual count. From 1923 to 1934, inclusive, yearly measurements have been taken of each tree, and yearly cumulative records, by rows, made of height growth, from which have been determined the averages for the respective rows. The number of trees per row shown by these records form the basis for the stand data. Height measurements are taken each fall, using a rod 20 feet long graduated in feet and tenths of feet. The natural branching, resulting in a large number of multiple-stemmed trees, has prevented diameter measurements being taken with a high degree of accuracy. This has prevented a study of diameter growth. Height growth, however, is of considerably more importance than the diameter growth in shelter belts planted purely for protection purposes.

The annual average heights shown in tables 4 to 25, inclusive, are computed from the measured heights of the individual trees comprising each row. The average heights shown in table 26 are the weighted averages of all rows of each species in each combination.

A decrease in the average height measurements for any row in a following year represents killing back of one or more trees in that row between the dates of measurements. A large increase in the average height measurements for any row in a following year is usually caused by one or more trees dying, which in the previous year had killed back severely, thereby reducing the average measurements for the row.

The stand data are expressed in percentage (percent stand) of the trees originally planted in the row. All trees that failed to become established the first year of planting were replaced the first spring following only. Tables 5 to 21, inclusive, show only the established stand after replacements were made. Tables 22 to 26, inclusive, show the stand for the first year of planting and the stand finally established after replacements were made.

EXPERIMENTAL DATA ON COMBINATIONS

The data on growth and survival of each combination are presented in tables 5 to 26. Discussion of these data is confined to explanatory statements of the behavior of certain species.

Eighteen species of trees were used to plant part or all of the 22 combination tests. All species of birch, willow, and poplar were unable to maintain satisfactory growth and survival under the limited precipitation and the competition of other species. An exception to this occurs in combinations 10, 11, and 12 where Russian golden willow, laurel willow, and poplar have maintained comparatively high survivals and suffered very little killing back. Combinations 10, 11, and 12 are situated in a small depression to which run-off water drains during periods of heavy rainfall. The favorable effects of this additional moisture are very clearly shown in a comparison of survival of laurel willow shown in figure 2.

TABLE 5.—*Annual average height and percentage of stand, by rows, of the species in combination 1, planted in 1915 and spaced 4 by 4 feet, at the Northern Great Plains Field Station, for the 18-year period 1917–34*

HEIGHT (FEET)

Species	Row no.	1917	1918	1919	1920	1921	1922	1923	1924	1925	1926	1927	1928	1929	1930	1931	1932	1933	1934
Gray birch	1	4.5	6.5	7.5	8.0	13.0	12.0	11.9	13.9	15.3	13.8	13.0	15.4	16.6	14.7	15.6	16.2	11.4	0
Green ash	2	4.5	5.5	7.0	9.5	11.6	10.7	12.0	14.1	15.5	16.7	16.4	17.4	18.1	19.4	20.2	21.1	21.9	21.7
Gray birch	3	4.0	6.0	6.5	8.0	8.5	4.5	0	0	0	0	0	0	0	0	0	0	0	0
Green ash	4	3.5	5.5	7.0	9.5	11.6	9.8	11.4	13.2	14.3	16.7	14.9	15.7	16.4	16.7	17.4	18.2	19.4	19.1
Gray birch	5	4.5	6.5	7.0	8.0	8.5	8.0	0	0	0	0	0	0	0	0	0	0	0	0
Green ash	6	5.0	7.0	8.5	9.5	11.6	10.7	11.9	13.9	14.8	15.3	15.5	16.0	17.3	17.8	18.7	19.8	19.2	17.9
Gray birch	7	4.0	5.5	8.5	8.0	9.5	11.0	11.0	12.5	13.0	0	0	0	0	0	0	0	0	0
Green ash	8	5.0	6.5	9.0	9.5	12.5	10.5	11.6	13.2	14.3	15.2	15.2	15.5	17.1	17.5	17.3	18.1	18.4	16.2
Gray birch	9	5.0	7.0	8.0	8.0	9.5	8.0	8.7	10.0	0	0	0	0	0	0	0	0	0	0
Green ash	10	4.5	5.5	8.0	9.5	12.0	10.4	11.7	13.5	14.5	15.0	15.3	15.8	17.0	17.2	18.3	18.6	19.1	18.2
Gray birch	11	5.0	6.0	8.0	8.0	12.0	6.5	9.0	10.9	11.4	0	0	0	0	0	0	0	0	0
Green ash	12	4.5	6.5	9.0	9.5	13.0	11.4	12.5	14.3	15.2	15.8	16.1	16.4	18.0	18.1	18.7	20.0	19.8	19.5

STAND (PERCENT)

Gray birch	1	68	68	64	64	56	52	48	48	48	48	40	40	24	24	24	24	20	0
Green ash	2	100	100	100	100	100	100	100	100	100	96	96	96	96	96	96	96	96	96
Gray birch	3	48	48	48	32	20	12	0	0	0	0	0	0	0	0	0	0	0	0
Green ash	4	96	96	96	96	96	96	96	96	96	96	96	96	96	96	96	96	92	84
Gray birch	5	52	52	52	20	4	4	0	0	0	0	0	0	0	0	0	0	0	0
Green ash	6	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Gray birch	7	64	64	64	24	20	4	4	4	4	0	0	0	0	0	0	0	0	0
Green ash	8	96	96	96	96	96	96	96	96	96	96	96	96	96	96	96	96	92	88
Gray birch	9	40	40	40	20	16	8	4	4	0	0	0	0	0	0	0	0	0	0
Green ash	10	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Gray birch	11	36	36	36	32	24	12	8	8	8	0	0	0	0	0	0	0	0	0
Green ash	12	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

FIGURE 2.—*A*, Laurel willow (right) and Russian golden willow (left) in combinations 11 and 12, respectively, planted in 1916 and spaced 4 by 8 feet, have maintained better than usual growth and survival owing to the site being in a small depression which collects run-off water from the surrounding land. *B*, Laurel willow (center row) almost entirely eliminated in combination 6, planted in 1915 and spaced 2 by 8 feet. This latter combination receives no run-off moisture; Northern Great Plains Field Station.

TABLE 6.—*Annual average height and percentage of stand, by rows, of the species in combination 2, planted in 1915 and spaced 4 by 4 feet, at the Northern Great Plains Field Station, for the 18-year period 1917–34*

HEIGHT (FEET)

Species	Row no.	1917	1918	1919	1920	1921	1922	1923	1924	1925	1926	1927	1928	1929	1930	1931	1932	1933	1934
Chokecherry	1	4.0	5.5	5.0	5.5	8.2	7.3	6.7	7.1	7.4	7.6	7.6	8.5	8.1	8.2	7.9	7.9	8.3	7.6
Do	2	4.5	5.5	5.5	6.5	9.0	8.3	7.5	8.4	8.6	8.7	8.4	9.0	8.8	8.6	8.8	8.8	9.1	7.8
Boxelder	3	7.0	9.0	10.0	9.5	12.8	11.8	13.4	14.6	14.9	16.0	16.0	16.1	17.3	17.2	17.8	18.6	19.0	19.5
Do	4	6.0	8.5	10.0	8.5	11.5	10.5	11.9	12.6	13.1	13.6	14.1	14.7	15.1	15.2	14.5	14.3	12.9	10.4
Green ash	5	4.5	5.5	5.5	7.5	10.1	9.5	10.6	12.2	13.6	14.0	14.6	15.0	16.5	16.4	16.0	16.5	16.9	16.7
Do	6	5.5	7.0	6.5	7.8	11.0	10.3	10.9	12.3	13.4	13.8	14.2	15.2	16.2	16.8	17.4	18.8	18.8	18.4
Carolina poplar	7	5.5	9.0	7.0	7.5	14.0	15.5	12.8	14.7	17.9	20.4	21.0	25.0	26.0	27.3	30.4	30.0	30.5	31.0
Do	8	6.0	6.5	7.0	6.0	11.0	9.0	5.5	7.0	0	0	0	0	0	0	0	0	0	0
Boxelder	9	5.5	6.5	7.0	7.5	11.0	9.8	10.4	11.1	11.5	12.0	12.0	12.5	13.0	13.1	13.3	14.4	14.3	9.6
Do	10	5.5	6.5	7.0	9.0	12.0	10.5	10.4	11.3	11.7	11.5	11.9	12.3	12.5	12.7	12.2	13.5	13.2	10.3
Laurel willow	11	4.5	6.5	5.0	5.2	7.3	7.0	5.9	7.5	7.9	8.0	0	0	0	0	0	0	0	0
Do	12	5.5	7.0	5.0	4.3	6.0	7.0	6.8	7.3	7.6	5.0	0	0	0	0	0	0	0	0
Russian golden willow	13	7.0	10.0	8.5	9.0	8.5	12.5	8.5	7.9	10.9	19.0	0	0	0	0	0	0	0	0
Do	14	7.0	10.0	8.5	8.5	14.5	12.0	9.0	10.0	11.5	17.9	0	0	0	0	0	0	0	0
Chokecherry	15	4.0	4.5	5.0	4.1	8.0	6.0	6.0	6.5	6.8	7.1	7.3	7.7	8.2	8.1	8.0	8.2	8.3	7.6
Do	16	4.0	3.5	3.5	4.1	7.5	5.7	4.3	5.2	5.5	5.7	6.0	6.4	6.3	6.8	7.0	7.5	7.8	7.9

STAND (PERCENT)

Chokecherry	1	92	92	88	88	88	88	84	84	84	84	84	84	84	84	84	84	80	80
Do	2	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92
Boxelder	3	100	100	100	100	100	100	100	96	92	92	92	92	92	92	92	92	92	92
Do	4	100	100	100	100	100	100	100	100	100	100	100	96	92	92	92	92	92	92
Green ash	5	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Do	6	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Carolina poplar	7	96	96	92	44	28	24	20	20	16	8	8	8	8	8	8	8	8	8
Do	8	100	96	68	28	8	4	4	4	0	0	0	0	0	0	0	0	0	0
Boxelder	9	100	100	100	100	100	100	100	100	100	96	96	96	96	96	96	96	96	88
Do	10	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92
Laurel willow	11	92	92	92	84	68	48	48	44	40	8	0	0	0	0	0	0	0	0
Do	12	100	100	100	96	96	84	84	80	72	8	0	0	0	0	0	0	0	0
Russian golden willow	13	100	96	96	96	96	56	40	40	32	4	0	0	0	0	0	0	0	0
Do	14	100	100	100	84	64	28	28	28	24	12	0	0	0	0	0	0	0	0
Chokecherry	15	92	92	92	92	92	92	88	88	88	88	88	88	88	88	88	88	84	76
Do	16	100	100	100	100	100	100	100	100	96	96	96	96	96	92	92	92	92	88

TABLE 7.—*Annual average height and percentage of stand, by rows, of the species in combination 3, planted in 1915 and spaced 4 by 4 feet, at the Northern Great Plains Field Station, for the 18-year period 1917–34*

HEIGHT (FEET)

Species	Row no.	1917	1918	1919	1920	1921	1922	1923	1924	1925	1926	1927	1928	1929	1930	1931	1932	1933	1934
American plum	1	3.5	4.5	5.5	[1]	9.5	8.0	7.9	8.1	8.4	8.2	7.9	7.3	7.6	6.9	6.6	7.3	7.8	7.8
Do	2	3.0	4.0	5.0	[1]	6.5	7.0	5.9	6.5	6.5	6.6	5.9	6.3	5.8	6.3	4.9	5.8	6.5	5.6
Boxelder	3	6.0	9.5	10.0	16.0	16.0	14.3	16.0	17.6	17.9	18.5	18.6	18.2	19.0	18.4	18.3	18.3	18.7	16.9
Green ash	4	3.5	5.5	8.0	8.0	13.0	11.7	12.7	13.7	14.4	14.6	14.6	15.1	15.7	15.7	15.5	15.8	16.2	15.6
Boxelder	5	7.0	9.5	9.0	13.0	16.5	12.5	14.2	15.1	15.6	15.8	16.1	16.8	17.5	17.0	16.6	16.9	16.9	11.2
Green ash	6	4.5	6.0	7.0	8.3	12.0	10.7	12.0	13.4	14.4	14.7	14.9	15.6	16.5	16.4	15.9	16.4	16.8	16.8
Boxelder	7	7.0	8.5	10.0	10.2	13.0	12.8	12.8	13.7	14.1	14.3	14.5	15.0	15.9	15.9	14.9	15.6	16.2	12.8
Green ash	8	5.0	6.5	6.5	6.2	7.5	9.9	10.3	11.9	12.5	13.0	12.9	13.6	14.4	14.5	13.7	14.3	14.5	14.5
Boxelder	9	7.0	9.0	9.0	9.0	10.1	11.8	11.9	12.7	12.8	13.3	13.7	14.4	15.6	15.7	15.8	16.8	16.4	16.0
Green ash	10	5.0	6.0	6.5	8.7	8.5	10.1	10.6	12.2	13.0	13.7	14.0	14.2	16.0	16.2	16.8	17.8	18.2	18.6
Carolina poplar	11	5.0	7.0	8.0	11.0	11.0	13.5	13.0	13.8	16.0	0	0	0	0	0	0	0	0	0
Russian golden willow	12	6.0	8.5	9.0	12.0	10.5	11.8	10.7	12.3	13.0	13.1	11.1	10.6	10.9	8.4	7.6	9.1	9.6	3.3
Carolina poplar	13	5.5	9.0	9.5	13.0	10.0	15.5	17.0	18.9	19.8	20.5	18.5	18.5	18.1	22.6	14.0	23.8	23.0	15.1

[1] No data collected.

TABLE 7.—*Annual average height and percentage of stand, by rows, of the species in combination 3, planted in 1915 and spaced 4 by 4 feet, at the Northern Great Plains Field Station, for the 18-year period 1917–34*—Continued

HEIGHT (FEET)—Continued

Species	Row no.	1917	1918	1919	1920	1921	1922	1923	1924	1925	1926	1927	1928	1929	1930	1931	1932	1933	1934
Russian golden willow	14	6.0	9.0	9.0	10.5	12.0	11.0	11.6	12.9	13.2	12.0	9.6	9.2	10.8	10.4	9.9	11.1	10.2	10.0
Carolina poplar	15	6.5	10.0	10.5	13.0	6.5	17.5	16.8	18.5	19.4	19.2	18.6	16.8	16.1	15.8	14.9	16.7	14.7	30.0
Russian golden willow	16	7.0	11.0	9.5	15.2	11.5	11.7	13.0	14.2	14.7	13.4	8.6	11.5	10.9	10.1	9.4	10.0	9.5	0
Carolina poplar	17	7.5	11.0	11.0	9.0	15.5	15.0	17.6	19.0	19.5	20.3	18.2	12.4	11.8	12.7	13.3	14.7	11.3	0
Russian golden willow	18	8.0	11.0	11.5	12.0	14.0	12.0	12.4	13.5	14.0	13.4	12.2	9.8	10.3	10.2	9.6	10.1	10.5	7.1
Diamond willow	19	6.0	7.0	9.0	8.5	10.5	8.5	10.0	9.9	10.4	8.5	7.5	7.5	7.7	7.3	6.6	6.5	5.8	6.2
Do	20	5.5	6.5	8.0	9.5	11.0	8.5	8.9	9.4	9.7	7.8	7.3	7.7	8.4	7.4	7.0	7.4	7.5	7.9
American plum	21	2.5	3.0	3.0	3.5	6.5	4.8	4.7	4.9	5.1	5.2	5.3	5.9	6.0	6.1	7.5	8.4	8.5	8.6
Do	22	3.5	4.0	4.0	4.5	7.7	5.3	6.4	6.5	6.8	6.5	6.5	6.6	6.9	6.9	8.0	8.7	8.9	8.7

STAND (PERCENT)

American plum	1	92	92	92	92	92	92	92	92	92	88	88	88	88	84	76	72	60	44
Do	2	88	88	88	88	88	72	72	68	64	48	48	36	32	32	32	24	16	16
Boxelder	3	100	100	100	96	96	96	96	96	96	96	96	96	96	96	96	96	92	92
Green ash	4	100	100	100	100	96	96	96	96	96	96	96	96	96	96	96	96	96	96
Boxelder	5	100	100	100	100	100	100	100	100	100	100	100	96	96	96	96	96	92	92
Green ash	6	100	96	96	96	96	96	96	96	96	96	96	96	96	96	96	96	96	96
Boxelder	7	100	100	100	100	100	100	100	100	100	100	100	100	100	96	92	92	88	88
Green ash	8	100	100	100	100	100	100	100	100	100	100	96	96	96	96	96	96	96	96
Boxelder	9	100	100	100	100	100	100	100	100	100	100	96	96	96	92	92	92	92	92
Green ash	10	100	100	100	100	100	100	100	100	100	100	100	96	96	96	96	96	96	96
Carolina poplar	11	92	88	84	48	24	16	8	8	4	4	0	0	0	0	0	0	0	0
Russian golden willow	12	100	96	96	96	96	96	96	96	96	44	20	20	16	16	16	16	16	4
Carolina poplar	13	84	76	72	64	52	48	44	40	32	24	16	16	8	8	8	4	4	4
Russian golden willow	14	100	100	100	96	96	96	96	96	96	92	88	84	64	56	56	52	48	4
Carolina poplar	15	96	96	92	88	76	72	64	64	60	56	52	48	36	36	36	36	36	4
Russian golden willow	16	100	100	100	100	100	100	100	100	100	84	84	84	80	80	80	76	72	0
Carolina poplar	17	100	100	96	80	76	72	68	68	64	56	52	48	40	36	28	28	28	0
Russian golden willow	18	100	100	100	100	100	96	96	92	92	80	76	68	64	60	60	60	48	12
Diamond willow	19	92	92	92	84	84	84	84	84	84	80	72	64	32	32	32	32	32	20
Do	20	72	68	68	68	64	64	64	64	64	64	56	52	32	32	28	28	24	16
American plum	21	88	88	88	88	88	88	88	84	76	76	76	76	76	76	76	76	76	72
Do	22	88	88	88	88	88	84	84	84	84	84	84	84	84	84	84	84	84	80

TABLE 8.—*Annual average height and percentage of stand, by rows, of the species in combination 4, planted in 1915 and spaced 4 by 4 feet, at the Northern Great Plains Field Station, for the 18-year period 1917–34*

HEIGHT (FEET)

Species	Row no.	1917	1918	1919	1920	1921	1922	1923	1924	1925	1926	1927	1928	1929	1930	1931	1932	1933	1934
Siberian pea-tree	1	3.5	4.5	4.5	5.0	7.0	6.0	6.3	7.0	7.1	7.5	7.6	7.8	8.5	8.7	9.0	9.0	9.0	9.0
Do	2	3.5	4.5	5.0	4.7	7.1	6.0	6.1	6.6	6.9	7.1	7.1	7.6	8.2	8.2	8.5	8.8	9.3	9.4
Green ash	3	4.5	6.0	5.5	6.0	6.6	7.9	8.9	10.6	11.7	12.0	12.2	12.3	13.3	13.7	12.5	12.8	11.5	6.7
Do	4	4.5	6.0	5.5	6.0	6.8	7.7	8.7	10.0	11.0	11.7	12.0	12.5	13.4	13.6	14.3	14.4	12.3	6.9
Do	5	4.5	6.0	5.5	6.7	7.1	7.9	8.8	10.2	11.0	11.7	11.9	12.5	13.2	13.5	13.5	14.3	13.6	11.1
Do	6	4.5	6.0	6.0	8.8	8.9	9.3	10.6	11.8	12.7	13.1	13.3	13.7	14.6	15.1	15.4	16.5	16.5	16.2
Carolina poplar	7	4.5	7.0	8.0	10.5	12.0	13.0	23.0	24.5	27.0	28.4	30.0	32.0	33.0	33.0	34.0	36.0	30.2	30.0
Do	8	5.5	6.5	8.0	9.0	17.0	13.0	20.9	22.8	24.0	24.9	24.5	34.0	35.0	35.0	35.0	36.0	33.0	34.0
Do	9	5.5	8.0	8.0	10.7	7.0	8.0	5.5	4.0	4.5	0	0	0	0	0	0	0	0	0
Do	10	7.0	9.0	8.0	8.3	10.7	13.0	22.0	24.0	26.0	27.6	30.0	33.0	34.0	33.0	32.0	35.0	36.0	35.0
Boxelder	11	6.0	8.0	8.0	8.8	10.0	10.5	11.6	12.2	13.0	13.2	13.8	13.6	13.6	13.6	13.9	14.8	14.1	12.3
Do	12	6.0	7.0	7.0	8.5	10.0	10.5	10.7	11.6	12.4	13.1	13.3	13.7	14.0	14.1	10.9	11.3	11.9	9.1
Do	13	6.0	7.0	7.0	8.0	9.6	10.5	10.9	11.7	12.2	12.8	13.1	14.0	13.5	13.4	13.0	13.5	13.2	11.4
Do	14	6.0	7.0	7.0	8.0	9.6	11.7	10.9	11.6	12.4	12.7	13.1	14.0	14.1	14.2	14.0	15.0	16.1	13.1
Laurel willow	15	5.0	6.0	5.7	7.2	9.1	8.0	6.4	7.1	7.8	5.0	7.0	8.5	0	0	0	0	0	0
Do	16	5.0	6.0	7.0	8.0	9.5	9.0	5.6	6.8	7.4	7.2	4.2	5.3	0	0	0	0	0	0
Do	17	5.0	7.0	7.0	9.0	12.0	13.0	6.6	9.4	9.6	13.2	13.1	12.1	14.5	13.5	13.3	13.2	14.0	0
Do	18	5.5	6.5	8.0	13.8	14.9	17.0	10.5	12.3	12.8	15.4	18.3	16.4	16.8	17.0	15.3	15.4	12.5	0
Siberian pea-tree	19	3.5	4.0	5.0	4.0	7.1	5.8	6.0	6.8	7.0	7.2	7.3	7.7	8.3	8.3	9.0	8.9	9.2	9.0
Do	20	3.5	4.5	5.0	4.7	7.1	6.0	6.6	7.0	7.4	7.6	7.8	8.2	9.2	9.3	9.7	10.0	10.1	10.1

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TABLE 8.—*Annual average height and percentage of stand, by rows, of the species in combination 4, planted in 1915 and spaced 4 by 4 feet, at the Northern Great Plains Field Station, for the 18-year period 1917–34*—Continued

STAND (PERCENT)

Species	Row no.	1917	1918	1919	1920	1921	1922	1923	1924	1925	1926	1927	1928	1929	1930	1931	1932	1933	1934
Siberian pea-tree	1	100	96	96	96	96	96	96	96	96	92	92	92	92	92	92	92	92	92
Do	2	100	100	100	100	100	100	100	100	100	96	96	92	92	92	92	92	88	84
Green ash	3	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	76	68
Do	4	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	96	80
Do	5	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	96
Do	6	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	96
Carolina poplar	7	96	88	80	56	16	12	12	8	4	4	4	4	4	4	4	4	4	4
Do	8	100	100	72	42	32	24	24	24	12	8	8	4	4	4	4	4	4	4
Do	9	96	96	68	40	12	8	4	4	4	0	0	0	0	0	0	0	0	0
Do	10	100	100	92	40	24	20	16	16	8	4	4	4	4	4	4	4	4	4
Boxelder	11	96	96	96	96	96	96	96	96	96	96	96	96	96	96	96	96	96	96
Do	12	100	100	100	100	100	100	100	100	100	100	100	96	96	96	92	92	84	80
Do	13	100	100	100	100	100	100	100	100	100	96	96	96	96	96	96	92	84	84
Do	14	96	96	96	96	96	96	96	96	96	96	96	96	96	96	96	96	88	88
Laurel willow	15	100	100	100	76	48	48	32	24	24	16	4	4	0	0	0	0	0	0
Do	16	100	100	100	84	80	64	56	56	52	24	16	16	0	0	0	0	0	0
Do	17	100	100	96	96	96	96	88	88	72	36	20	16	12	12	12	12	8	0
Do	18	96	96	96	92	88	60	60	60	60	44	28	28	20	20	12	12	12	0
Siberian pea-tree	19	100	100	100	96	96	96	96	88	88	88	88	88	84	84	84	84	80	80
Do	20	100	100	100	100	100	100	96	92	92	92	92	80	76	76	76	76	76	76

TABLE 9.—*Annual average height and percentage of stand, by rows, of the species in combination 5, planted in 1915 and spaced 2 by 8 feet, at the Northern Great Plains Field Station, for the 18-year period 1917–34*

HEIGHT (FEET)

Species	Row no.	1917	1918	1919	1920	1921	1922	1923	1924	1925	1926	1927	1928	1929	1930	1931	1932	1933	1934
Siberian pea-tree	1	4.0	4.5	5.0	5.5	7.9	6.0	6.5	7.1	7.3	7.4	7.3	7.8	8.8	9.1	9.6	9.6	10.1	10.4
Do	2	4.0	4.5	5.0	5.4	7.0	5.8	6.3	7.1	7.4	7.8	7.9	8.2	9.0	9.1	9.4	9.5	9.6	10.0
Boxelder	3	6.5	8.0	9.0	11.0	12.0	13.5	14.5	15.6	16.3	17.0	17.2	17.3	18.3	17.5	17.9	17.7	18.7	17.3
Do	4	6.5	9.0	9.5	11.2	12.0	13.3	13.5	14.3	14.7	15.3	15.5	16.5	16.8	16.4	13.6	14.5	15.8	12.2
Green ash	5	3.5	4.5	4.5	5.5	7.5	6.3	7.2	8.3	9.1	9.8	10.3	11.1	12.3	12.3	12.1	12.4	12.4	12.9
Do	6	4.7	6.5	7.5	7.5	10.5	10.0	11.2	12.7	13.8	14.5	15.0	16.4	17.7	18.0	18.3	18.1	18.8	19.0
Carolina poplar	7	5.0	11.0	12.0	14.0	20.0	20.7	19.9	21.6	22.2	24.5	24.8	25.5	24.8	24.8	22.2	25.3	27.8	27.7
Do	8	5.5	11.0	12.0	11.5	19.0	19.5	19.0	21.5	22.0	24.2	22.6	26.2	25.4	24.4	24.7	25.1	26.0	28.2
Boxelder	9	6.0	9.0	11.0	8.5	11.0	14.5	14.1	14.7	15.2	15.6	15.7	15.3	16.1	16.0	14.9	15.6	15.1	13.4
Do	10	5.0	7.5	9.0	10.7	10.2	11.8	13.4	14.1	14.6	15.2	15.3	16.1	16.2	15.6	15.2	16.0	15.5	12.2
Laurel willow	11	5.5	8.0	10.5	12.5	10.7	13.8	15.9	17.0	17.8	16.8	17.0	17.1	17.8	18.1	11.8	12.0	11.2	5.8
Do	12	5.0	7.5	10.5	13.0	10.7	13.8	14.7	16.6	17.5	15.6	16.5	15.1	15.4	12.5	8.9	9.3	9.5	6.3
Russian golden willow	13	6.5	10.5	13.0	11.5	13.2	17.0	18.4	19.3	19.5	18.8	18.8	15.8	15.2	12.3	10.6	12.2	11.4	6.9
Do	14	3.5	6.5	8.0	9.5	9.5	14.0	14.4	15.4	15.5	16.8	17.3	16.4	16.3	13.6	11.9	13.0	13.8	4.0
Siberian pea-tree	15	3.5	4.0	4.5	4.5	6.5	6.2	6.4	7.0	7.5	7.7	8.0	8.4	9.1	9.6	10.4	10.5	10.9	10.8
Do	16	3.5	4.5	4.5	5.1	7.3	7.0	7.2	7.7	8.3	8.7	8.9	9.6	10.0	10.0	10.5	11.0	11.2	11.4

STAND (PERCENT)

Siberian pea-tree	1	100	98	98	98	98	98	94	94	94	92	88	88	86	86	84	84	84	78
Do	2	100	98	96	96	96	96	96	96	96	92	92	92	90	88	88	86	84	80
Boxelder	3	100	98	98	98	98	98	98	96	96	96	96	96	96	96	96	96	96	94
Do	4	100	98	98	98	98	98	98	98	98	98	98	98	98	98	98	90	82	80
Green ash	5	98	98	98	98	98	98	96	96	96	96	96	96	96	96	96	96	92	86
Do	6	98	98	98	98	98	98	98	98	96	96	96	96	96	96	96	96	96	92
Carolina poplar	7	96	96	84	70	62	56	48	48	42	34	30	30	26	24	24	22	20	14
Do	8	84	84	74	52	36	36	30	28	28	20	20	18	14	14	14	14	12	8
Boxelder	9	100	100	100	100	100	100	100	98	98	96	96	96	82	80	80	78	78	78
Do	10	96	96	96	96	96	96	96	92	92	88	88	86	86	86	86	86	86	90
Laurel willow	11	100	98	98	98	98	98	92	92	92	62	62	38	36	36	36	36	32	20
Do	12	100	98	98	98	98	94	94	90	90	84	84	54	44	44	44	40	30	18
Russian golden willow	13	100	100	98	98	96	96	96	94	94	60	60	40	34	34	34	34	20	16
Do	14	100	100	100	100	88	82	80	78	78	40	38	30	24	24	24	24	18	8
Siberian pea-tree	15	100	100	100	100	100	100	100	100	100	98	98	98	96	96	94	94	94	92
Do	16	100	98	98	98	98	98	98	96	96	92	90	90	90	90	88	88	86	84

TABLE 10.—*Annual average height and percentage of stand, by rows, of the species in combination 6, planted in 1915 and spaced 2 by 8 feet, at the Northern Great Plains Field Station, for the 18-year period 1917–34*

HEIGHT (FEET)

Species	Row no.	1917	1918	1919	1920	1921	1922	1923	1924	1925	1926	1927	1928	1929	1930	1931	1932	1933	1934
Siberian pea-tree	1	3.5	4.5	4.5	4.7	7.7	6.5	6.8	7.8	8.1	8.4	8.8	9.2	9.8	10.3	10.7	10.7	11.8	11.9
Do	2	3.5	4.5	4.5	5.0	7.1	6.0	6.8	7.8	8.3	8.3	8.4	9.3	9.6	10.1	10.4	10.4	11.0	11.3
Green ash	3	3.5	4.5	5.6	4.9	7.7	6.9	7.6	9.1	10.0	10.1	10.2	11.1	12.0	12.3	12.2	12.6	12.3	9.9
Boxelder	4	6.0	8.5	10.5	11.4	13.0	13.0	14.5	15.0	15.5	15.8	15.6	16.3	16.3	16.1	14.6	14.9	16.3	12.9
Green ash	5	3.5	4.0	4.6	5.5	6.5	6.7	7.5	8.6	9.6	9.9	10.2	10.7	11.3	11.6	11.6	12.0	12.2	12.2
Boxelder	6	6.5	8.5	10.5	12.5	12.0	13.0	13.9	14.0	14.4	14.6	14.6	15.2	15.1	14.9	12.6	12.7	13.0	9.3
Green ash	7	3.5	4.0	5.0	5.5	6.1	5.2	6.1	7.3	8.3	8.7	9.1	10.1	11.1	12.4	11.3	11.8	11.9	12.3
Boxelder	8	6.0	8.0	9.5	10.7	12.5	13.0	13.0	13.0	13.3	13.6	13.5	14.3	14.3	14.0	11.4	12.1	13.1	9.7
Green ash	9	3.0	3.7	4.5	5.5	6.1	6.2	6.3	7.4	8.2	8.9	9.4	10.4	10.9	11.7	11.0	11.4	12.1	11.6
Boxelder	10	5.5	7.5	9.5	11.2	11.6	13.0	12.9	13.3	13.6	13.7	13.2	14.7	14.6	14.3	13.7	14.3	14.0	10.6
Carolina poplar	11	6.5	11.0	11.0	10.5	10.5	9.5	13.6	16.3	18.3	20.0	23.0	21.0	21.4	20.9	10.9	19.0	19.2	0
Laurel wi'low	12	5.5	7.5	10.0	8.5	8.0	7.7	8.2	9.6	10.0	6.7	6.6	7.3	8.8	8.8	9.2	9.8	8.7	0
Carolina poplar	13	5.5	7.5	7.5	11.5	11.2	11.5	14.0	16.2	17.6	20.3	24.2	21.8	19.1	21.6	17.3	18.7	20.0	11.1
Laurel willow	14	5.5	7.0	5.0	7.5	7.5	6.5	7.6	9.0	9.2	7.3	5.6	7.7	8.3	8.4	9.2	10.1	7.6	0
Carolina poplar	15	7.5	10.5	11.5	11.5	11.7	11.5	14.6	16.5	17.2	18.7	21.0	18.3	17.0	15.3	14.7	15.2	14.1	19.7
Laurel willow	16	5.5	6.0	5.0	6.5	6.7	6.5	6.5	7.7	7.8	5.7	4.9	7.0	6.8	6.9	8.2	9.8	7.2	0
Carolina poplar	17	8.5	10.5	12.0	12.0	9.5	11.5	13.6	15.0	16.5	19.9	20.4	22.8	21.2	20.0	14.8	16.1	14.1	11.6
Laurel willow	18	5.5	7.0	5.0	5.6	6.5	5.8	5.4	6.3	6.5	0	0	0	0	0	0	0	0	0
Siberian pea-tree	19	3.5	4.0	4.5	5.1	6.9	6.0	6.6	7.2	7.6	7.8	8.1	8.4	9.1	9.4	9.9	10.2	10.6	10.6
Do	20	3.0	4.2	4.5	3.5	7.0	6.0	6.3	7.0	7.5	7.5	7.8	8.0	9.0	9.2	9.6	9.8	10.0	10.4

STAND (PERCENT)

Siberian pea-tree	1	96	96	96	96	96	96	94	94	90	88	80	78	78	76	76	76	72	70
Do	1	98	96	94	94	92	92	92	92	90	88	88	86	86	86	84	84	84	78
Green ash	3	98	98	98	98	98	98	98	98	96	96	96	94	92	92	92	92	92	88
Boxelder	4	100	100	100	100	100	100	100	98	98	98	96	96	94	94	90	90	80	80
Green ash	5	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	98
Boxelder	6	100	100	100	100	100	100	100	100	100	98	92	92	92	92	92	90	84	82
Green ash	7	100	100	100	100	100	100	100	100	98	96	96	94	94	92	92	92	90	88
Boxelder	8	100	98	98	98	98	98	98	98	98	98	98	92	92	92	92	88	76	72
Green ash	9	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	96	94
Boxelder	10	98	98	98	98	98	98	98	98	96	96	96	96	96	96	96	96	96	92
Carolina poplar	11	92	80	70	58	44	38	34	30	24	12	4	4	4	4	4	2	2	0
Laurel willow	12	100	100	100	100	88	88	74	74	74	46	38	32	20	20	20	20	14	0
Carolina poplar	13	82	78	68	56	54	46	42	36	32	28	22	20	14	14	14	14	10	4
Laurel willow	14	98	98	96	96	88	88	78	78	66	50	42	40	40	40	40	40	34	0
Carolina poplar	15	96	94	88	82	70	66	58	56	54	46	38	30	30	28	28	28	20	4
Laurel willow	16	98	98	98	98	86	82	76	72	68	52	40	32	28	28	28	28	28	0
Carolina poplar	17	90	90	88	68	64	58	58	54	42	26	22	20	18	18	18	18	16	6
Laurel willow	18	90	90	90	90	78	62	48	44	42	0	0	0	0	0	0	0	0	0
Siberian pea-tree	19	94	90	90	90	90	90	90	88	86	82	80	78	78	78	78	78	78	78
Do	20	94	94	94	94	94	94	94	94	94	92	90	90	86	84	84	84	84	80

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TABLE 11.—*Annual average height and percentage of stand, by rows, of the species in combination 7, planted in 1915 and spaced 4 by 4 feet, at the Northern Great Plains Field Station, for the 18-year period 1917–34*

HEIGHT (FEET)

Species	Row no.	1917	1918	1919	1920	1921	1922	1923	1924	1925	1926	1927	1928	1929	1930	1931	1932	1933	1934
Green ash	1	4.0	5.0	6.0	7.0	9.6	9.8	10.9	12.5	13.9	14.0	14.3	14.6	16.0	16.5	16.5	16.9	17.4	17.5
Russian golden willow	2	6.5	10.5	11.0	12.0	12.5	11.0	11.7	12.6	13.8	14.0	9.5	0	0	0	0	0	0	0
Green ash	3	4.5	5.5	6.0	7.0	8.0	9.4	10.2	11.4	12.4	12.8	13.2	13.6	14.1	14.4	14.7	15.2	15.5	15.9
Russian golden willow	4	5.5	7.0	8.5	10.0	10.5	10.5	7.2	7.9	10.3	0	0	0	0	0	0	0	0	0
Green ash	5	4.0	4.5	5.5	7.7	7.5	9.1	10.4	11.2	12.4	12.8	13.3	13.2	14.1	14.7	14.8	15.7	15.7	16.1
Russian golden willow	6	6.0	7.0	8.0	8.5	12.0	12.5	11.8	12.3	13.9	10.2	12.8	8.6	11.3	11.1	9.2	12.2	0	0
Green ash	7	4.0	5.5	7.0	6.7	7.2	9.5	10.2	11.7	12.9	13.4	13.7	14.4	15.1	15.5	15.6	16.1	16.7	16.4
Russian golden willow	8	7.0	10.5	10.0	11.7	12.0	12.3	11.0	11.2	12.9	10.7	9.7	10.8	11.6	11.1	9.3	10.7	0	0

STAND (PERCENT)

Green ash	1	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Russian golden willow	2	100	100	100	100	92	88	76	72	72	12	8	0	0	0	0	0	0	0
Green ash	3	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Russian golden willow	4	100	100	100	100	96	96	72	68	40	0	0	0	0	0	0	0	0	0
Green ash	5	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	96
Russian golden willow	6	100	100	100	100	96	96	96	96	92	28	16	16	8	8	8	4	0	0
Green ash	7	100	100	100	100	100	100	100	100	100	100	96	96	96	96	96	96	96	96
Russian golden willow	8	100	100	100	100	100	100	100	100	100	44	32	28	28	24	24	20	0	0

TABLE 12.—*Annual average height and percentage of stand, by rows, of the species in combination 8, planted in 1916 and spaced 4 by 8 feet, at the Northern Great Plains Field Station, for the 18-year period 1917–34*

HEIGHT (FEET)

Species	Row no.	1917	1918	1919	1920	1921	1922	1923	1924	1925	1926	1927	1928	1929	1930	1931	1932	1933	1934
Siberian pea-tree	1	2.0	3.0	3.5	3.1	5.4	5.0	5.4	6.4	6.5	7.4	7.7	8.4	8.8	9.3	10.0	10.0	10.4	10.5
Laurel willow	2	3.7	6.0	7.0	7.8	7.5	8.0	7.2	7.0	8.1	10.6	10.5	12.0	0	0	0	0	0	0

STAND (PERCENT)

Siberian pea-tree	1	100	100	100	100	100	100	100	100	92	88	88	88	88	88	84	84	84	84
Laurel willow	2	100	100	100	100	100	100	96	96	92	8	4	4	0	0	0	0	0	0

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TABLE 13.—*Annual average height and percentage of stand, by rows, of the species in combination 9, planted in 1916 and spaced 4 by 8 feet, at the Northern Great Plains Field Station, for the 18-year period 1917–34*

HEIGHT (FEET)

Species	Row no.	1917	1918	1919	1920	1921	1922	1923	1924	1925	1926	1927	1928	1929	1930	1931	1932	1933	1934
Siberian pea-tree	1	1.8	3.0	3.5	3.5	4.7	5.0	5.7	6.4	7.0	7.8	7.7	8.1	8.8	9.1	9.8	10.2	10.4	10.7
Carolina poplar	2	4.5	9.0	10.0	11.5	12.6	14.0	14.9	16.8	17.9	22.3	22.3	17.9	20.2	22.4	22.5	24.8	27.4	25.9
Laurel willow	3	2.0	5.8	7.6	8.6	7.6	7.5	6.8	7.0	8.6	10.1	13.7	14.1	14.3	10.8	5.6	6.2	4.8	0

STAND (PERCENT)

Siberian pea-tree	1	100	100	100	100	100	100	100	100	96	96	96	96	96	96	96	96	96	96
Carolina poplar	2	92	92	92	92	88	88	80	76	68	20	16	16	16	16	16	16	16	16
Laurel willow	3	88	88	88	88	84	84	80	76	76	36	16	8	8	8	8	8	8	0

TABLE 14.—*Annual average height and percentage of stand, by rows, of the species in combination 10, planted in 1916 and spaced 4 by 8 feet, at the Northern Great Plains Field Station, for the 18-year period 1917–34*

HEIGHT (FEET)

Species	Row no.	1917	1918	1919	1920	1921	1922	1923	1924	1925	1926	1927	1928	1929	1930	1931	1932	1933	1934
Siberian pea-tree	1	2.0	3.0	3.5	3.5	4.5	4.3	5.5	6.3	7.0	7.5	7.5	8.0	8.6	8.9	9.5	9.4	10.4	10.7
Norway poplar	2	4.5	9.0	11.0	11.5	12.7	17.0	19.9	23.3	22.9	25.4	24.4	26.7	27.8	29.2	28.2	30.7	33.1	29.6
Boxelder	3	3.5	5.5	6.0	7.7	9.4	11.5	11.6	14.0	15.1	15.9	16.1	16.9	18.5	19.2	18.5	20.0	21.4	21.2
Laurel willow	4	3.5	6.5	8.0	8.6	8.7	9.7	11.0	12.9	14.4	12.9	15.4	17.2	18.6	18.2	15.6	20.9	14.9	3.5

STAND (PERCENT)

Siberian pea-tree	1	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	96	92
Norway poplar	2	92	92	92	92	88	88	80	76	72	64	64	64	56	56	56	56	52	52
Boxelder	3	100	100	100	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92
Laurel willow	4	64	64	64	48	48	48	44	44	44	40	36	28	20	16	12	8	8	4

TABLE 15.—*Annual average height and percentage of stand, by rows, of the species in combination 11, planted in 1916 and spaced 4 by 8 feet, at the Northern Great Plains Field Station, for the 18-year period 1917–34*

HEIGHT (FEET)

Species	Row no.	1917	1918	1919	1920	1921	1922	1923	1924	1925	1926	1927	1928	1929	1930	1931	1932	1933	1934
Russian golden willow	1	3.5	8.5	10.5	10.0	10.5	14.8	17.5	19.6	21.0	20.9	21.1	23.4	23.6	23.1	21.9	22.7	23.5	20.8
Boxelder	2	2.5	4.5	6.0	6.5	7.7	11.0	12.4	13.7	15.2	15.5	16.0	16.9	18.0	18.2	18.2	19.5	20.7	20.2
Poplar	3	3.5	6.5	9.0	10.0	11.8	15.2	18.0	20.1	21.8	23.8	26.0	29.4	30.1	32.0	32.1	35.1	35.4	36.7
Boxelder	4	3.0	5.0	6.5	8.5	10.1	13.3	14.5	15.3	17.1	17.7	17.7	19.4	20.2	20.2	21.3	21.9	23.4	23.2
Laurel willow	5	3.5	6.5	8.6	10.0	10.0	14.5	15.3	18.4	19.8	20.5	20.7	24.0	26.0	28.1	25.9	25.6	26.3	26.6

STAND (PERCENT)

Russian golden willow	1	100	100	100	100	100	100	100	100	100	96	96	96	96	92	92	88	80	68
Boxelder	2	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Poplar	3	40	40	40	40	40	40	40	40	40	36	28	28	28	28	28	28	28	28
Boxelder	4	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Laurel willow	5	84	84	84	80	76	76	76	72	72	72	64	64	60	52	52	52	52	48

TABLE 16.—*Annual average height and percentage of stand, by rows, of the species in combination 12, planted in 1916 and spaced 4 by 8 feet, at the Northern Great Plains Field Station, for the 18-year period 1917–34*

HEIGHT (FEET)

Species	Row no.	1917	1918	1919	1920	1921	1922	1923	1924	1925	1926	1927	1928	1929	1930	1931	1932	1933	1934
Russian golden willow	1	4.0	8.0	10.0	11.5	9.3	12.5	17.9	20.3	20.4	23.5	23.5	26.9	26.0	28.1	23.5	25.5	26.3	28.9
Poplar	2	3.5	6.5	9.0	9.6	11.1	13.0	20.8	23.1	24.1	26.8	28.1	32.1	30.1	33.8	35.1	35.4	34.4	33.1
Boxelder	3	3.5	5.0	7.0	5.9	7.6	10.7	11.6	13.1	14.5	14.5	15.0	16.4	16.8	17.0	18.2	18.9	21.1	21.0
Poplar	4	4.0	8.0	8.5	9.0	8.8	14.5	17.8	20.5	21.0	23.1	24.1	27.0	27.3	26.0	27.2	31.3	31.3	28.9
Boxelder	5	3.5	5.5	8.0	7.6	9.0	11.5	13.7	14.7	16.0	16.3	16.7	17.6	18.9	19.3	18.8	20.7	21.6	21.0
Laurel willow	6	4.5	7.5	8.5	8.8	8.0	10.2	12.6	15.2	15.7	17.6	17.4	18.8	19.7	19.7	20.2	20.3	19.9	20.6

STAND (PERCENT)

Species	Row no.	1917	1918	1919	1920	1921	1922	1923	1924	1925	1926	1927	1928	1929	1930	1931	1932	1933	1934
Russian golden willow	1	88	88	88	88	88	88	88	84	84	80	76	76	76	76	76	76	76	60
Poplar	2	36	36	36	36	36	36	36	36	32	32	32	32	32	32	32	32	32	32
Boxelder	3	100	100	100	100	100	100	100	100	100	100	100	96	96	96	96	96	92	92
Poplar	4	60	60	60	60	56	56	56	52	48	36	36	36	36	36	36	36	36	36
Boxelder	5	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Laurel willow	6	84	84	84	84	84	84	80	80	76	56	56	56	56	56	56	56	56	48

TABLE 17.—*Annual average height and percentage of stand, by rows, of the species in combination 13, planted in 1916 and spaced 4 by 8 feet, at the Northern Great Plains Field Station, for the 18-year period 1917–34*

HEIGHT (FEET)

Species	Row no.	1917	1918	1919	1920	1921	1922	1923	1924	1925	1926	1927	1928	1929	1930	1931	1932	1933	1934
Siberian pea-tree	1	2.0	3.5	3.5	3.2	4.4	5.0	5.4	6.3	6.8	7.2	7.5	8.1	8.7	8.8	9.2	9.6	10.1	10.1
Laurel willow	2	4.0	6.5	7.5	10.0	8.9	9.0	9.1	10.6	11.5	12.5	12.6	13.7	15.1	15.8	13.2	14.0	14.5	13.7
Poplar	3	4.5	8.0	11.0	12.0	10.1	17.5	15.8	18.8	21.1	22.0	22.7	21.6	21.6	25.2	22.7	24.2	23.6	27.8
Russian golden willow	4	4.5	8.0	8.5	9.5	8.3	10.0	10.9	12.1	14.0	13.8	13.7	18.5	17.3	14.2	15.5	17.3	15.1	5.4
Poplar	5	4.0	8.0	9.0	11.6	10.0	15.5	15.4	17.9	20.2	20.9	20.7	22.5	21.9	22.2	20.5	22.1	24.0	16.8
Russian golden willow	6	4.0	7.0	9.0	9.7	9.1	12.0	11.5	12.5	13.6	14.3	13.3	16.1	15.0	14.4	12.8	14.6	12.8	9.5
Poplar	7	4.0	8.0	9.5	10.6	11.0	18.0	16.7	19.2	20.2	21.2	21.9	24.8	24.9	24.4	20.6	20.0	20.0	10.5
Russian golden willow	8	4.0	7.0	9.0	10.0	9.5	13.0	11.9	13.0	13.9	13.4	12.8	12.9	14.0	12.6	10.1	11.5	11.2	3.5

STAND (PERCENT)

Species	Row no.	1917	1918	1919	1920	1921	1922	1923	1924	1925	1926	1927	1928	1929	1930	1931	1932	1933	1934
Siberian pea-tree	1	100	100	100	100	100	100	100	100	96	96	96	96	96	96	96	96	96	96
Laurel willow	2	96	96	92	92	92	92	92	92	76	60	56	52	48	44	44	44	40	36
Poplar	3	88	88	88	88	88	84	84	84	80	64	64	60	48	44	36	36	32	20
Russian golden willow	4	92	92	92	92	92	92	88	88	80	32	24	12	12	8	8	8	8	8
Poplar	5	76	76	76	72	72	72	64	64	56	52	44	44	40	40	36	36	24	8
Russian golden willow	6	92	92	92	92	92	92	88	88	88	60	44	36	32	32	32	32	32	12
Poplar	7	76	76	76	76	68	68	64	64	64	56	52	52	52	52	52	52	44	24
Russian golden willow	8	88	88	88	88	88	88	88	84	84	76	56	52	48	48	48	48	40	4

TABLE 18.—*Annual average height and percentage of stand, by rows, of the species in combination 14, planted in 1916 and spaced 4 by 8 feet, at the Northern Great Plains Field Station, for the 18-year period 1917–34*

HEIGHT (FEET)

Species	Row no.	1917	1918	1919	1920	1921	1922	1923	1924	1925	1926	1927	1928	1929	1930	1931	1932	1933	1934
Laurel willow	1	4.0	6.0	7.0	8.7	7.9	9.3	9.3	10.1	10.8	10.5	10.2	11.3	10.6	8.3	7.0	7.7	7.9	0
Do	2	3.5	5.5	7.0	8.5	8.5	9.0	9.0	9.9	11.0	10.0	9.2	9.7	10.5	10.0	7.7	8.9	6.4	0
Poplar	3	4.5	8.0	9.5	10.7	12.6	18.8	16.4	18.3	19.6	19.2	17.9	17.5	19.0	19.8	19.2	19.8	21.2	7.0
Boxelder	4	3.0	5.5	7.0	8.5	7.1	12.7	13.0	15.0	15.9	16.4	16.1	16.9	16.9	17.5	17.5	19.6	20.0	20.4
Poplar	5	4.0	9.0	10.5	10.2	10.0	14.2	12.0	14.1	15.0	17.0	12.0	0	0	0	0	0	0	0
Boxelder	6	3.0	5.5	7.0	8.5	10.0	11.0	13.2	14.5	15.4	15.7	15.9	16.4	16.6	16.8	15.9	18.1	18.2	11.7
Poplar	7	4.5	9.0	9.5	8.6	10.5	16.0	15.6	17.3	18.9	21.7	24.5	24.3	26.0	25.9	24.4	27.7	27.0	15.5
Boxelder	8	3.0	5.5	7.0	8.6	10.5	11.5	12.6	14.0	14.8	15.3	15.2	16.1	15.5	15.5	16.3	18.1	18.8	16.7
Poplar	9	4.5	9.0	10.0	12.5	11.3	18.0	16.6	18.3	19.5	20.6	24.1	28.3	25.7	30.7	18.2	19.4	20.7	26.0
Russian golden willow	10	3.5	7.0	9.0	9.1	9.2	10.5	10.0	10.7	11.5	10.0	10.0	10.7	10.8	10.0	9.8	7.5	0	0

STAND (PERCENT)

Laurel willow	1	100	100	100	100	100	100	100	100	100	100	96	76	68	64	60	44	32	0
Do	2	84	84	84	84	84	84	84	84	84	84	68	48	44	44	44	44	32	0
Poplar	3	76	76	76	76	72	72	64	64	60	56	48	40	40	40	40	40	24	4
Boxelder	4	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Poplar	5	60	60	60	60	56	52	48	32	32	4	4	0	0	0	0	0	0	0
Boxelder	6	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Poplar	7	80	80	80	64	64	56	36	32	32	16	12	12	12	12	12	8	8	4
Boxelder	8	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Poplar	9	92	92	92	92	92	80	64	60	56	48	32	28	28	28	24	24	16	8
Russian golden willow	10	100	100	100	100	100	100	100	100	100	20	8	4	4	4	4	4	0	0

TABLE 19.—*Annual average height and percentage of stand, by rows, of the species in combination 15, planted in 1916 and spaced 4 by 4 feet, at the Northern Great Plains Field Station, for the 18-year period 1917–34*

HEIGHT (FEET)

Species	Row no.	1917	1918	1919	1920	1921	1922	1923	1924	1925	1926	1927	1928	1929	1930	1931	1932	1933	1934
Laurel willow	1	4.5	5.5	7.0	8.5	8.1	9.5	8.3	8.9	9.4	6.4	6.0	6.2	7.0	6.9	8.6	9.5	0	0
Do	2	4.5	6.5	7.0	7.9	7.6	9.3	7.4	8.0	9.1	8.9	8.0	6.0	7.0	5.6	6.1	5.2	8.7	0
Boxelder	3	3.0	5.0	7.0	6.5	6.6	10.0	10.9	12.3	12.9	13.2	13.7	14.2	14.6	14.6	13.3	13.9	14.9	12.4
Do	4	3.0	5.5	7.0	6.6	6.7	10.0	11.2	12.7	13.4	13.7	14.0	14.6	14.4	14.3	13.8	15.2	15.0	9.8
Green ash	5	2.0	3.5	4.5	5.5	5.0	6.6	7.6	8.9	10.4	11.1	11.9	11.8	12.4	12.4	12.5	13.6	14.4	14.4
Do	6	2.0	2.5	3.0	3.9	5.2	5.7	6.3	7.4	8.4	9.0	9.5	10.0	10.0	10.1	10.1	10.8	11.6	11.7
Boxelder	7	3.5	6.0	7.5	8.0	9.3	11.0	11.6	12.5	13.0	13.1	13.4	13.5	13.7	13.6	13.6	14.1	14.1	9.6
Do	8	3.5	5.5	7.5	9.2	7.6	10.0	10.8	11.7	12.3	12.6	12.8	13.5	13.5	13.1	11.7	12.9	12.7	8.0
Poplar	9	4.5	7.5	8.0	9.8	8.5	10.0	0	0	0	0	0	0	0	0	0	0	0	0
Do	10	4.5	7.0	8.0	10.0	9.5	16.5	17.5	18.8	18.2	0	0	0	0	0	0	0	0	0
Boxelder	11	3.5	5.5	7.0	7.2	9.6	10.0	10.9	12.3	12.9	13.2	13.4	13.4	13.8	13.7	13.0	14.6	14.7	10.5
Do	12	3.5	6.0	7.0	7.2	6.7	10.5	10.8	11.4	12.4	13.2	13.3	13.6	13.5	13.3	12.7	14.0	14.8	9.4
Poplar	13	4.0	7.0	7.0	7.5	6.9	10.5	5.5	6.5	7.0	0	0	0	0	0	0	0	0	0
Do	14	4.0	7.0	7.5	7.5	7.2	10.0	12.5	14.3	16.5	16.0	0	0	0	0	0	0	0	0
Boxelder	15	3.0	5.5	7.0	7.1	8.9	10.0	11.6	12.4	13.1	13.5	13.9	13.9	14.1	13.4	13.2	15.2	15.8	13.3
Do	16	3.0	5.0	7.0	6.7	7.1	10.0	11.1	12.4	13.0	13.4	13.6	13.8	13.7	13.4	13.6	14.6	15.1	11.7
Laurel willow	17	3.5	6.0	7.0	7.5	6.0	8.0	8.0	8.9	10.2	10.3	12.1	12.0	13.0	12.5	7.9	8.2	0	0
Do	18	3.5	6.0	7.0	7.0	6.4	8.0	8.0	8.8	10.1	10.1	10.1	5.4	5.3	4.4	4.0	0	0	0

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TABLE 19.—*Annual average height and percentage of stand, by rows, of the species in combination 15, planted in 1916 and spaced 4 by 4 feet, at the Northern Great Plains Field Station, for the 18-year period 1917–34*—Continued

STAND (PERCENT)

Species	Row no.	1917	1918	1919	1920	1921	1922	1923	1924	1925	1926	1927	1928	1929	1930	1931	1932	1933	1934
Laurel willow	1	100	100	100	100	100	100	100	100	100	48	12	12	12	12	12	12	0	0
Do	2	100	100	100	92	80	80	64	60	48	28	20	20	16	16	16	16	8	0
Boxelder	3	100	100	100	100	100	100	100	100	96	96	96	96	96	96	96	96	92	88
Do	4	100	100	100	100	100	100	100	100	96	96	96	92	88	88	88	88	84	76
Green ash	5	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Do	6	100	100	100	100	100	100	100	100	100	100	100	96	96	96	96	96	96	96
Boxelder	7	100	100	100	100	100	100	100	100	100	100	100	100	92	92	92	92	92	88
Do	8	100	100	100	100	100	100	100	100	100	100	100	92	92	92	92	92	92	92
Poplar	9	92	92	84	44	20	8	0	0	0	0	0	0	0	0	0	0	0	0
Do	10	92	92	88	64	24	16	8	8	8	0	0	0	0	0	0	0	0	0
Boxelder	11	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Do	12	100	100	100	100	100	100	100	100	100	100	100	96	92	92	92	92	88	88
Poplar	13	88	84	84	72	16	12	12	4	4	0	0	0	0	0	0	0	0	0
Do	14	92	92	92	52	32	12	4	4	4	4	0	0	0	0	0	0	0	0
Boxelder	15	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	92
Do	16	100	100	100	100	100	100	100	100	100	100	100	92	92	92	92	92	92	92
Laurel willow	17	88	88	88	88	64	64	52	48	40	32	28	12	12	12	12	8	0	0
Do	18	96	96	96	96	92	92	84	72	56	28	24	20	4	4	4	0	0	0

TABLE 20.—*Annual average height and percentage of stand, by rows, of the species in combination 16, planted in 1916 and spaced 4 by 4 feet, at the Northern Great Plains Field Station, for the 18-year period 1917–34*

HEIGHT (FEET)

Species	Row no.	1917	1918	1919	1920	1921	1922	1923	1924	1925	1926	1927	1928	1929	1930	1931	1932	1933	1934
Boxelder	[1] 1	2.5	5.0	6.5	8.5	8.6	12.3	11.9	13.0	13.6	13.7	13.8	14.3	14.6	14.3	14.0	14.4	14.7	8.8
Russian golden willow	2	4.5	8.0	9.5	6.0	6.1	6.5	7.7	8.4	10.4	0	0	0	0	0	0	0	0	0
Boxelder	3	3.0	5.5	7.5	8.0	10.2	12.0	12.3	13.1	13.6	13.8	13.9	14.5	14.9	14.5	13.8	14.1	13.8	8.9
Poplar	4	4.5	8.0	9.0	10.5	11.3	14.5	13.6	15.0	16.0	18.0	18.5	13.0	11.8	7.5	9.0	0	0	0
Boxelder	5	2.5	5.0	7.0	9.0	9.0	11.0	12.1	12.9	13.6	13.8	14.2	14.5	14.7	14.1	12.8	14.7	13.7	7.8
Green ash	6	1.8	2.5	3.0	4.2	4.1	6.8	7.2	8.1	8.8	9.3	9.4	9.8	9.7	9.7	9.5	9.7	10.5	10.6
Boxelder	7	3.2	5.0	7.0	7.9	8.6	11.3	12.3	13.2	13.5	14.1	14.4	14.8	15.0	14.2	13.5	14.3	14.3	8.6
Laurel willow	8	4.0	6.5	7.2	9.0	8.5	11.3	6.0	7.0	7.8	0	0	0	0	0	0	0	0	0
Boxelder	[1] 9	2.5	5.0	7.5	8.5	10.1	12.0	12.5	13.8	14.2	14.3	14.7	15.7	15.6	14.4	13.5	13.8	13.5	7.2

STAND (PERCENT)

Species	Row no.	1917	1918	1919	1920	1921	1922	1923	1924	1925	1926	1927	1928	1929	1930	1931	1932	1933	1934
Boxelder	[1] 1	98	98	98	98	98	98	98	98	98	98	98	94	92	90	90	90	86	86
Russian golden willow	2	100	100	100	68	28	24	20	20	20	0	0	0	0	0	0	0	0	0
Boxelder	3	100	100	100	100	100	100	100	100	100	100	100	100	96	96	96	96	96	92
Poplar	4	88	88	88	88	68	60	56	56	44	12	4	4	4	4	4	0	0	0
Boxelder	5	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Green ash	6	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Boxelder	7	100	100	100	100	100	100	100	100	100	100	96	96	92	92	92	92	92	88
Laurel willow	8	72	72	72	48	16	12	8	4	4	0	0	0	0	0	0	0	0	0
Boxelder	[1] 9	98	98	98	96	96	96	96	96	96	96	96	94	94	94	92	92	90	88

[1] Spaced 2 feet apart in the row.

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TABLE 21.—*Annual average height and percentage of stand, by rows, of the species in combination 17, planted in 1916 and spaced 4 by 4 feet, at the Northern Great Plains Field Station, for the 18-year period 1917–34*

HEIGHT (FEET)

Species	Row no.	1917	1918	1919	1920	1921	1922	1923	1924	1925	1926	1927	1928	1929	1930	1931	1932	1933	1934
Siberian pea-tree	[1] 1	2.0	3.5	3.5	4.0	5.8	5.0	5.3	6.1	6.4	6.5	6.7	7.3	7.7	8.2	8.2	8.4	8.9	8.9
Boxelder	2	2.5	4.5	7.0	7.0	7.9	11.5	13.2	14.6	15.4	15.9	15.8	16.6	17.2	16.2	15.2	15.8	15.2	8.4
Green ash	3	1.8	2.8	4.5	5.6	4.8	7.0	7.8	9.1	9.7	10.1	9.7	9.7	10.6	10.5	10.6	11.4	11.7	12.0
Laurel willow	[1] 4	3.5	6.0	8.0	10.9	9.5	12.0	10.6	11.4	13.3	0	0	0	0	0	0	0	0	0

STAND (PERCENT)

Siberian pea-tree	[1] 1	96	96	96	94	92	92	92	92	92	92	86	84	84	82	82	80	80	80
Boxelder	2	100	100	100	100	100	100	100	100	100	100	100	96	92	92	92	92	92	84
Green ash	3	96	96	96	96	96	96	96	96	96	96	96	96	96	96	96	96	96	96
Laurel willow	[1] 4	96	88	88	88	86	87	78	78	62	0	0	0	0	0	0	0	0	0

[1] Spaced 2 feet apart in the row.

TABLE 22.—*Annual average height and percentage of stand, by rows, of the species in combination 18, planted in 1917 and spaced 6 by 12 feet, at the Northern Great Plains Field Station, for the 18-year period 1917–34*

HEIGHT (FEET)

Species	Row no.	1917	1918	1919	1920	1921	1922	1923	1924	1925	1926	1927	1928	1929	1930	1931	1932	1933	1934
Boxelder	1	1.5	4.0	5.5	7.2	8.5	10.5	11.6	12.9	14.2	14.0	13.6	14.5	14.4	14.9	15.2	16.6	13.7	2.8
Green ash	2	1.2	2.5	3.5	4.0	4.6	6.9	8.1	10.0	10.9	11.9	12.4	14.3	14.8	15.8	17.0	17.6	17.4	18.9
Chinese elm	3	2.5	4.5	8.0	9.8	11.5	14.4	16.4	18.7	19.8	20.3	21.1	22.3	23.3	23.6	23.7	24.3	24.6	25.0
Northwest poplar	4	2.5	6.0	8.7	9.5	12.5	16.4	17.1	18.7	19.8	20.9	20.2	22.6	24.2	22.8	18.5	18.0	25.5	0
Birch	5	1.2	3.0	4.0	5.5	5.0	5.8	5.0	6.4	7.5	6.9	5.3	6.0	7.4	8.4	8.6	9.5	9.9	0
Sharpleaf willow	6	2.0	3.5	4.5	8.0	8.3	9.5	12.0	13.0	13.9	14.7	16.0	17.0	16.3	16.8	14.0	14.9	13.1	15.0

STAND (PERCENT)

Boxelder	1	[1] 77	94	94	94	94	94	94	94	94	94	94	94	94	94	94	94	94	82
Green ash	2	[1] 94	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Chinese elm	3	[1] 100	94	94	94	94	94	94	94	94	94	94	94	94	94	94	94	94	88
Northwest poplar	4	[1] 94	94	94	94	94	94	94	94	94	94	88	77	77	71	59	41	6	0
Birch	5	[1] 94	71	71	71	71	71	71	71	71	53	24	24	24	24	12	12	6	0
Sharpleaf willow	6	[1] 53	100	100	100	100	100	100	100	94	94	88	82	71	65	65	53	47	12

[1] Percentage of stand which became established in 1917. All losses were replaced in the spring of 1918.

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TABLE 23.—*Annual average height and percentage of stand, by rows, of the species in combination 19, planted in 1917 and spaced 4 by 4 feet, at the Northern Great Plains Field Station, for the 18-year period 1917–34*

HEIGHT (FEET)

Species	Row no.	1917	1918	1919	1920	1921	1922	1923	1924	1925	1926	1927	1928	1929	1930	1931	1932	1933	1934
Buffaloberry	1	0.6	2.0	3.0	2.5	5.5	4.5	5.8	6.2	6.9	6.8	6.9	7.9	8.4	8.0	8.5	8.5	8.6	8.3
Sharpleaf willow	2	1.2	3.0	4.0	6.0	7.0	8.0	10.2	11.2	12.3	13.6	13.2	14.0	15.1	14.4	11.4	11.9	15.8	12.2
Boxelder	3	1.2	4.0	5.0	7.5	9.1	11.5	13.7	15.2	15.5	16.3	16.0	16.3	17.2	16.8	17.8	18.2	18.1	9.9
Green ash	4	1.2	2.0	3.0	4.2	5.5	6.8	7.8	8.4	8.7	9.2	9.3	10.0	10.0	10.1	10.2	10.5	10.7	10.7
Chinese elm	5	2.5	4.5	7.5	8.2	9.8	13.7	15.5	17.5	18.6	19.0	19.2	20.8	21.6	21.6	22.6	22.6	22.8	22.9
Northwest poplar	6	1.8	6.0	8.0	10.1	10.7	14.9	15.8	17.6	19.3	19.3	19.5	20.0	22.9	23.4	15.8	17.1	25.3	0
Birch	7	1.2	2.5	3.0	4.2	5.0	5.5	5.1	6.2	6.2	0	0	0	0	0	0	0	0	0
Green ash	8	1.0	2.0	4.0	4.0	4.6	5.8	7.0	8.0	8.7	9.5	10.0	10.7	11.8	12.4	11.7	12.6	13.0	13.2
Boxelder	9	1.2	3.5	5.0	7.0	8.1	9.5	11.6	12.8	13.6	14.0	13.8	14.1	14.3	14.4	13.8	14.4	8.9	6.8
Sharpleaf willow	10	1.2	3.5	4.5	7.0	7.0	7.5	6.8	7.9	9.2	7.3	0	0	0	0	0	0	0	0

STAND (PERCENT)

Buffaloberry	1	[1] 56	44	44	44	44	44	44	44	40	40	40	40	40	40	40	40	40	36
Sharpleaf willow	2	[1] 28	96	96	96	92	88	84	84	84	52	32	32	32	28	28	2 4	12	8
Boxelder	3	[1] 100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	92
Green ash	4	[1] 100	96	96	96	96	96	96	96	96	96	96	96	96	96	96	96	96	96
Chinese elm	5	[1] 100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Northwest poplar	6	[1] 100	100	100	100	100	100	96	96	96	80	68	60	44	40	36	32	8	0
Birch	7	[1] 72	72	72	72	68	68	56	48	32	8	0	0	0	0	0	0	0	0
Green ash	8	[1] 84	96	96	96	96	96	96	96	96	96	96	96	96	96	96	96	96	96
Boxelder	9	[1] 68	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Sharpleaf willow	10	[1] 28	72	72	72	68	64	64	64	56	12	0	0	0	0	0	0	0	0

[1] Percentage of stand which became established in 1917. All losses were replaced in the spring of 1918.

TABLE 24.—*Annual average height and percentage of stand, by rows, of the species in combination 20, planted in 1917 and spaced 4 by 8 feet, at the Northern Great Plains Field Station, for the 18-year period 1917–34*

HEIGHT (FEET)

Species	Row no.	1917	1918	1919	1920	1921	1922	1923	1924	1925	1926	1927	1928	1929	1930	1931	1932	1933	1934
Buffaloberry	1	0.7	1.5	3.0	3.0	4.5	4.8	5.3	6.9	7.1	6.9	7.5	8.2	8.5	8.7	9.1	9.8	8.2	8.0
Boxelder	2	1.5	4.0	5.5	6.0	8.8	10.5	11.1	11.9	12.5	12.6	12.4	12.8	13.0	13.1	12.8	13.4	11.7	2.9
Chinese elm	3	2.5	5.0	7.5	8.5	11.5	13.5	16.4	18.1	19.3	19.7	19.2	21.4	22.1	22.1	22.4	24.1	24.0	23.7
Birch	4	1.2	2.5	4.5	3.6	4.8	6.0	4.8	5.3	5.5	3.3	0	0	0	0	0	0	0	0
Sharpleaf willow	5	1.2	3.0	5.0	5.0	6.0	6.5	7.8	8.5	9.4	9.5	10.4	11.5	11.6	9.6	8.1	6.6	6.9	0

STAND (PERCENT)

Buffaloberry	1	[1] 8	28	28	28	28	28	28	24	24	24	20	20	20	20	20	20	20	20
Boxelder	2	[1] 84	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	48
Chinese elm	3	[1] 96	92	92	92	88	88	88	88	88	88	88	88	88	88	88	88	88	88
Birch	4	[1] 76	72	72	72	68	68	68	64	60	24	0	0	0	0	0	0	0	0
Sharpleaf willow	5	[1] 16	96	96	96	92	92	92	88	84	76	48	56	44	44	44	40	12	0

[1] Percentage of stand which became established in 1917. All losses were replaced in the spring of 1918.

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TABLE 25.—*Annual average height and percentage of stand, by rows, of the species in combination 21, planted in 1917 and spaced 4 by 4 feet, at the Northern Great Plains Field Station, for the 18-year period 1917–34*

HEIGHT (FEET)

Species	Row no.	1917	1918	1919	1920	1921	1922	1923	1924	1925	1926	1927	1928	1929	1930	1931	1932	1933	1934
Buffaloberry	1	0.5	1.2	2.0	2.7	3.2	5.5	5.7	6.2	8.2	8.2	8.3	8.3	8.6	8.2	9.0	10.4	10.4	10.3
Sharpleaf willow	2	.7	2.5	3.0	5.7	6.0	6.3	6.4	7.5	8.1	9.4	9.7	10.2	10.4	11.6	8.4	10.5	12.2	0
Red willow	3	2.0	4.0	5.0	9.0	8.5	12.5	14.5	13.5	14.5	14.8	15.3	15.5	15.5	12.5	0	0	0	0
Boxelder	4	1.5	4.5	5.0	7.0	7.4	8.5	10.3	11.0	11.7	11.9	12.4	12.7	12.7	12.7	12.3	12.4	11.7	7.0
Birch	5	1.2	2.5	4.0	4.7	5.4	6.8	7.4	8.2	8.7	7.6	7.2	9.9	10.1	11.0	10.3	10.4	12.3	0
Boxelder	6	1.2	3.5	5.0	4.7	6.6	8.0	7.6	8.3	8.6	8.7	9.2	9.4	9.5	9.6	9.2	9.4	8.2	3.9
Green ash	7	1.2	2.5	3.5	4.5	4.6	5.4	6.3	7.1	8.0	8.7	9.7	10.3	10.7	11.4	11.4	12.6	13.2	13.5
Boxelder	8	1.2	3.5	4.5	4.0	5.5	7.0	7.2	7.6	8.0	8.2	8.7	9.0	9.5	8.6	6.7	6.5	4.8	3.9
Northwest poplar	9	2.5	6.0	7.2	9.0	9.1	12.5	13.8	15.6	17.2	17.3	17.4	19.2	20.8	20.5	19.0	19.8	18.1	0
Chinese elm	10	2.5	5.0	7.2	7.5	9.5	11.3	12.9	14.3	15.7	15.7	16.1	17.3	18.4	17.6	19.0	19.9	20.2	20.9
Boxelder	11	1.2	4.5	5.5	5.5	6.0	7.5	8.8	9.8	9.9	10.3	10.6	10.8	10.2	9.1	7.5	6.3	5.4	3.5
Green ash	12	1.0	1.5	2.5	2.5	3.6	4.7	5.4	6.0	6.9	7.1	7.6	8.1	8.5	8.7	8.3	8.8	9.1	9.3
Birch	13	1.1	2.5	3.5	4.0	5.5	4.0	5.0	5.8	6.7	6.6	7.0	8.6	7.7	6.4	6.2	7.2	6.6	0
Northwest poplar	14	2.0	6.0	7.0	7.0	10.0	13.0	13.0	14.8	16.8	16.7	17.0	19.4	20.0	20.1	15.8	17.4	21.9	20.3
Boxelder	15	1.5	3.5	4.5	3.8	6.2	8.0	7.9	8.5	8.7	9.0	9.5	9.7	9.7	9.5	9.3	9.0	9.2	9.2
Green ash	16	1.2	2.5	3.5	4.0	4.1	5.1	5.9	7.0	7.6	7.9	8.3	9.2	9.7	9.7	9.7	10.0	10.4	10.5
Birch	17	1.0	2.5	4.0	3.5	5.2	4.2	5.1	5.6	5.9	5.3	5.7	6.4	7.0	7.6	6.8	7.4	6.7	0
Red willow	18	1.2	3.0	3.5	7.0	9.0	10.0	11.0	6.6	8.0	8.8	9.8	9.5	8.9	9.1	9.5	9.3	10.5	0
Sharpleaf willow	19	2.0	3.5	4.0	4.2	5.0	6.0	6.8	7.2	7.7	8.1	8.0	8.9	9.0	8.6	8.9	8.3	8.0	8.4
Birch	20	.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

STAND (PERCENT)

Buffaloberry	1	[1] 4	52	52	52	32	20	16	12	12	12	8	8	8	8	8	8	8	8
Sharpleaf willow	2	[1] 4	64	64	64	64	64	64	64	64	60	60	52	44	40	40	32	24	0
Red willow	3	[1] 8	12	12	8	8	8	8	8	8	8	8	8	8	8	0	0	0	0
Boxelder	4	[1] 96	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Birch	5	[1] 56	44	44	44	44	40	40	40	40	40	40	32	28	28	28	28	24	0
Boxelder	6	[1] 48	96	96	92	92	92	92	92	92	92	88	88	84	84	84	84	84	80
Green ash	7	[1] 96	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92
Boxelder	8	[1] 52	100	100	96	96	96	96	96	96	96	96	80	80	80	76	76	76	52
Northwest poplar	9	[1] 80	92	92	92	92	92	88	84	80	80	80	80	80	80	80	80	28	0
Chinese elm	10	[1] 96	96	96	96	96	96	96	96	96	96	96	96	96	96	92	92	92	92
Boxelder	11	[1] 84	100	100	100	100	96	96	96	96	96	96	96	96	96	96	96	92	76
Green ash	12	[1] 64	96	96	96	96	96	96	96	96	96	96	96	96	92	92	92	92	92
Birch	13	[1] 68	68	68	68	68	68	68	64	56	48	44	36	28	28	24	24	16	0
Northwest poplar	14	[1] 84	88	88	88	88	88	88	88	88	88	84	84	84	84	80	72	40	16
Boxelder	15	[1] 36	92	92	92	88	88	88	88	88	88	88	88	88	88	88	88	88	84
Green ash	16	[1] 80	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92
Birch	17	[1] 56	44	44	44	44	44	44	44	44	36	36	36	36	36	36	36	36	0
Red willow	18	[1] 20	16	16	16	16	16	16	16	16	16	16	12	12	12	12	12	8	0
Sharpleaf willow	19	[1] 76	80	80	80	80	80	80	80	80	80	76	76	76	76	76	76	68	24
Birch	20	[1] 4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

[1] Percentage of stand which became established in 1917. All losses were replaced in the spring of 1918.

TABLE 26.—*Annual average height and percentage of stand, by rows, of the species in combination 22, planted in 1917 and spaced 4 by 8 feet, at the Northern Great Plains Field Station, for the 18-year period 1917–34*

HEIGHT (FEET)

Species	Row no.	1917	1918	1919	1920	1921	1922	1923	1924	1925	1926	1927	1928	1929	1930	1931	1932	1933	1934
Buffaloberry	[1] 1	0.7	2.0	3.0	4.5	4.7	5.0	5.9	7.1	8.2	8.2	8.4	8.9	9.2	9.5	9.7	10.0	10.1	10.0
Sharpleaf willow	2	1.8	3.5	4.0	5.0	5.7	6.2	5.6	6.8	7.6	6.6	0	0	0	0	0	0	0	0
Birch	3	1.8	2.5	4.5	4.1	6.8	7.3	5.2	6.0	6.6	5.2	5.1	6.9	8.2	7.3	8.1	8.6	4.2	0
Northwest poplar	4	2.0	6.5	8.8	12.0	13.0	15.4	16.4	18.2	19.8	19.9	20.0	20.5	21.4	24.2	13.1	16.8	19.3	0
Chinese elm	5	2.0	5.5	8.0	9.5	11.7	12.1	14.1	16.4	17.5	18.0	19.0	19.5	20.0	21.1	21.2	22.0	22.1	22.3
Birch	6	1.2	3.0	4.0	5.5	5.5	5.0	3.9	4.9	6.0	0	0	0	0	0	0	0	0	0
Green ash	7	1.2	2.5	4.0	4.7	6.2	7.2	8.4	10.1	11.3	12.2	12.7	13.9	15.6	15.7	16.8	17.6	18.2	18.4
Boxelder	8	1.2	3.0	5.0	6.8	10.0	9.0	10.5	12.1	13.9	13.1	13.1	13.4	14.3	13.9	14.5	15.2	14.4	11.9
Red willow	9	1.0	5.0	4.5	7.0	9.2	11.0	12.0	13.3	14.5	0	0	0	0	0	0	0	0	0
Birch	[1] 10	1.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

[1] Spaced 2 feet apart in the row.

TABLE 26.—*Annual average height and percentage of stand, by rows, of the species in combination 22, planted in 1915 and spaced 4 by 8 feet, at the Northern Great Plains Field Station, for the 18-year period 1917–34*—Continued

STAND (PERCENT)

Species	Row no.	1917	1918	1919	1920	1921	1922	1923	1924	1925	1926	1927	1928	1929	1930	1931	1932	1933	1934
Buffaloberry	[1] 1	[2] 42	60	56	56	56	56	56	56	56	56	56	56	56	56	56	56	54	52
Sharpleaf willow	2	[2] 32	96	96	96	96	92	80	68	68	8	0	0	0	0	0	0	0	0
Birch	3	[2] 64	52	52	52	52	48	48	48	48	40	32	32	32	32	32	32	20	0
Northwest poplar	4	[2] 88	88	88	88	88	88	88	88	88	88	76	72	64	56	44	32	12	0
Chinese elm	5	[2] 92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	88
Birch	6	[2] 60	44	44	44	44	24	24	20	16	0	0	0	0	0	0	0	0	0
Green ash	7	[2] 96	88	88	88	88	88	88	88	88	88	88	88	88	88	88	88	88	88
Boxelder	8	[2] 32	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	92	60
Red willow	9	[2] 4	8	8	8	8	4	4	4	4	0	0	0	0	0	0	0	0	0
Birch	[1] 10	[2] 4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

[1] Spaced 2 feet apart in the row.
[2] Percentage of stand which became established in 1917. All losses were replaced in the spring of 1918.

Trees in combination 21 have the poorest site of any of the series. The land slopes sharply to the south and west, and the soil is of poorer quality than elsewhere in the series.

Hedge-type species having boxelder in adjacent rows have been badly suppressed or forced outward by the spreading side branches of boxelder. This suppression has resulted in a number of trees of American plum, rows 1 and 2, combination 3, being killed. This is particularly noticeable in row 2, which is adjacent to the boxelder in row 3. American plum in rows 21 and 22 of the same combination is removed from this influence and shows comparatively high survivals. The effects of this suppression by boxelder have not been so serious on chokecherry and Siberian pea-tree. The tops of many of these trees, however, have been bent outward and pushed over for some distance away from the center of the row. Green ash does not develop spreading side branches and has caused no suppression of hedge species in adjacent rows.

Green ash planted in single rows between rows of boxelder has also suffered from side-crowding or suppression by the boxelder. The result of this suppression is reflected in the growth of green ash, as shown in figure 3. Some trees have made no measurable increases in height growth since actual measurements were first started. Note the small diameter growth of the ash trees as compared with the diameter growth of the boxelder in adjacent rows in figure 3. Green ash planted in double or quadruple rows makes considerably better growth than when planted with the same spacing distance in single rows between rows of boxelder. Figure 4 shows double and quadruple rows of green ash comparable in age and spacing distance with the single rows shown in figure 3.

Boxelder has developed many spreading side branches, except in combinations where it was planted in a row adjacent to a faster growing species, such as Northwest poplar or Chinese elm. In such locations the faster growing species has prevented excessive side branching of the boxelder and has more or less suppressed the rate of height growth. Figure 5 shows a single row of boxelder planted adjacent to green ash and a single row of boxelder planted

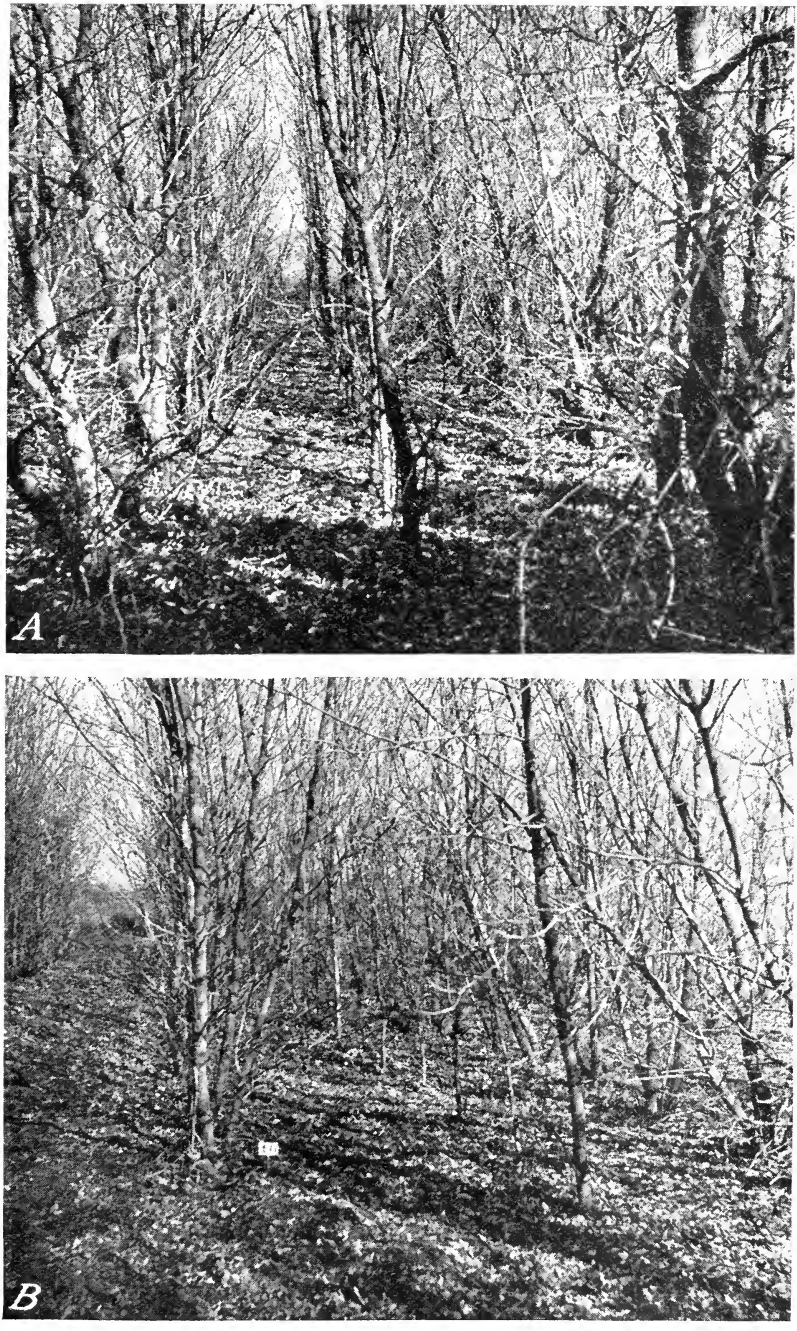

FIGURE 3.—Green ash is badly crowded and suppressed when planted in single rows between rows of boxelder: *A*, Green ash (center) in combination 3, planted in 1915 and spaced 4 by 4 feet. *B*, Green ash (right of center) in combination 16, planted in 1916 and spaced 4 by 4 feet. Note the small diameter growth of ash, particularly in *B;* Northern Great Plains Field Station.

FIGURE 4.—Green ash makes better growth when planted in double rows *A* and quadruple rows *B* than when planted in single rows between boxelder, as shown in figure 3. *A* is combination 2 and *B* is combination 4. Both combinations were planted in 1915 and spaced 4 by 4 feet; Northern Great Plains Field Station.

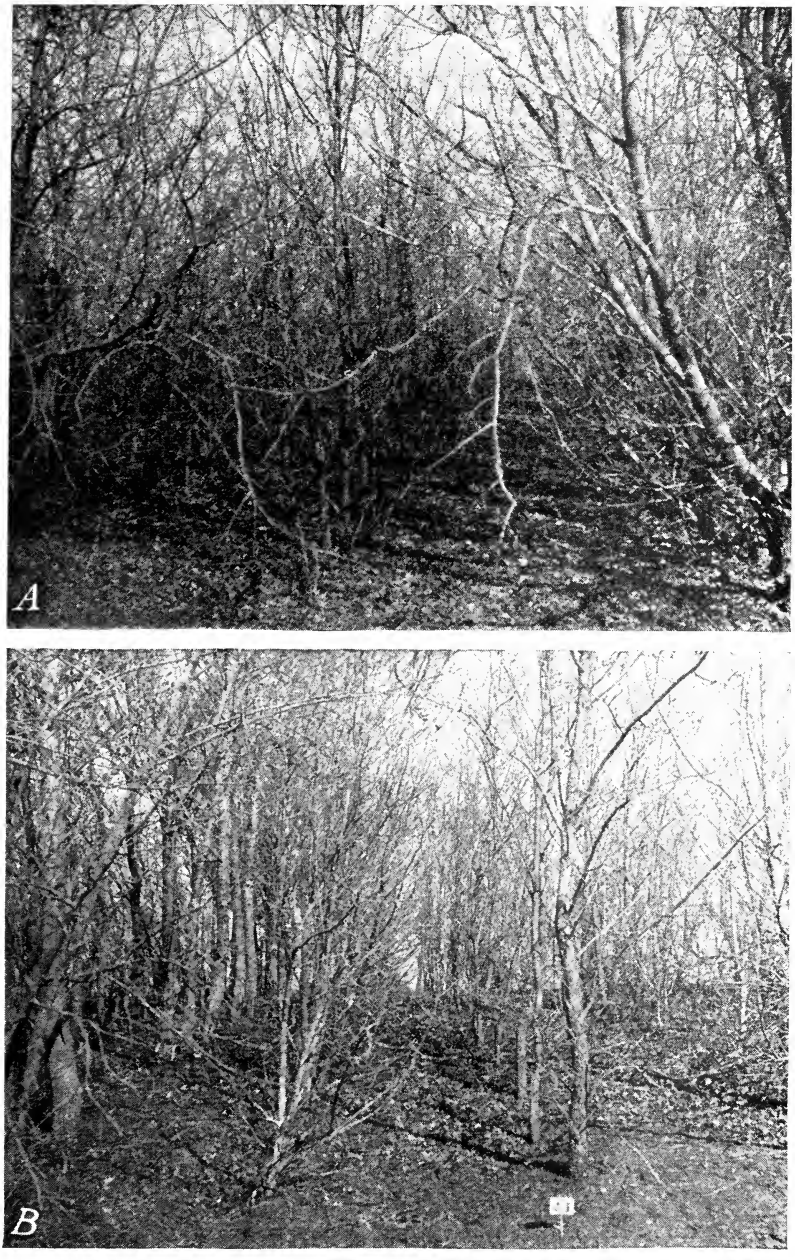

FIGURE 5.—*A*, Boxelder (right) planted adjacent to green ash rows in combination 6, spaced 2 by 8 feet, has developed spreading side branches and suffered no suppression. *B*, Boxelder (center row) has been badly suppressed by the faster growing Northwest poplar (left) in the adjacent row in combination 21 planted in 1917 and spaced 4 by 4 feet. Note the differences in diameter growth and spread of side branches in *A* and *B*; Northern Great Plains Field Station.

adjacent to a row of Northwest poplar. Note the differences in diameter growth and spread of side branches.

Chinese elm, in all combinations in which it occurs, has made a rapid height growth and has not been subject to any serious side crowding or overtopping influences by adjacent species. It has developed wide-spreading side branches in combinations having the wider spacing distances and in other combinations where species in adjacent rows have died out. Figure 6 shows the development of side branches of Chinese elm in combination 22 as compared with the almost total absence of lower side branches in combination 19.

All willow and boxelder species, and to a less extent the other species, have developed multiple-stemmed trees. The two former species sprout prolifically from the base and along the lower part of the stems. Growth that kills back has, in many cases, been replaced by new shoot growth from the base, particularly in the case of willows. All the green ash, boxelder, chokecherry, Siberian pea-tree, and American plum sections have developed a dense overhead shade, which has prevented any undergrowth and for many years has done away with the necessity for cultivation. The denseness of the plantings and the leaf litter covering the ground can be observed in figures 3, 4, and 5. These sections also act effectively in breaking wind and holding snow, which passes into the interior of the belt. Poplar, willow, and birch sections have killed out so badly that constant cultivation is required to prevent weed growth, and the stands have been opened up to such an extent that they are worthless for wind and snow protection. This condition is shown in figure 2, *B*, where the poplar and willow are almost entirely eliminated.

The desirability of maintaining a tight planting, which prevents grass and weed growth and also prevents leaves from being blown away, so that a leaf litter may be formed on the ground, becomes very apparent in the different sections of the combinations. The tight planting holds more snow, and the accumulated leaf litter readily absorbs all moisture and prevents excessive loss by evaporation.

EFFECT OF SPACING DISTANCE ON HEIGHT AND STAND

A summary of the average height, the number of trees surviving, and the percentage of a complete stand in 1933 and 1934 of each species used in the 22 shelter-belt combinations is given in table 27. Data for the year 1933 have been included for comparison purposes with those of 1934. The degree of killing back and losses in stand which occurred during 1934 as a result of the severe drought conditions that year can thus be readily ascertained. Precipitation during 1934 totaled 8.13 inches and followed a year of 11.91 inches, which was 3.08 inches below normal. The height in each case is the average of all surviving trees of the given species in that particular combination. Measurements were made at the end of the growing season. The spacing distances used were 4 by 4, 2 by 8, 4 by 8, and 6 by 12 feet. Trees in outside rows were spaced 2 feet apart in three combinations otherwise spaced 4 by 4 feet and in two combinations otherwise spaced 4 by 8 feet. Thirteen species were planted in combinations having two or more spacing distances. Five species were planted in one combination and spacing distance only.

Considerable variation in average growth is shown for a given species within each spacing distance. For certain species these dif-

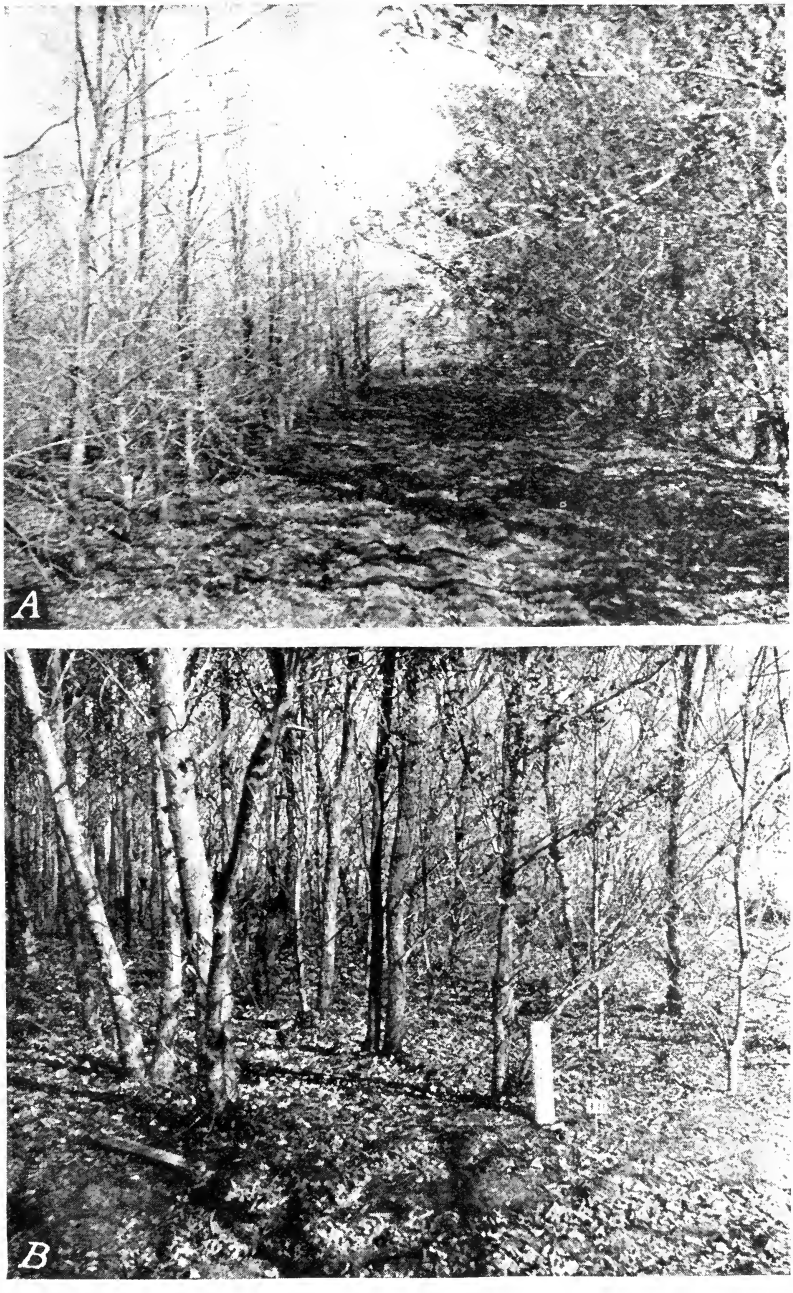

FIGURE 6.—*A*, Chinese elm (right) in combination 22, planted in 1917 and spaced 4 by 8 feet, has developed side branches extending almost across the vacant birch row to the green ash row 16 feet away. *B*, Chinese elm (row marked by white stake) in combination 19, planted in 1917 and spaced 4 by 4 feet, is almost free of side branches; Northern Great Plains Field Station.

ferences can be traced to the position occupied by the species in the combination in relation to the species in adjacent rows. The differences in growth and survival of other species, particularly the survival, are dependent more on the inherent qualities of the species themselves than on the spacing distance or the relation of adjacent species. The lack of these qualities has been manifested without regard to spacing distance or combination employed. Conditions of soil and moisture may counteract this defect to some extent, as in the case of willows in combinations 11 and 12, but will not overcome it, except perhaps under favorable conditions, such as have not been presented in these experiments.

TABLE 27.—*Average height, number of trees alive, and percentage of survival in 1933 and 1934 of species grown in different spacing distances in 22 shelter-belt combinations at the Northern Great Plains Field Station* [1]

Species	Spaced 2 by 8 feet							Spaced 4 by 4 feet							Spaced 4 by 8 feet							Spaced 6 by 12 feet						
	Combination no.	Height		Survival				Combination no.	Height		Survival				Combination no.	Height		Survival				Combination no.	Height		Survival			
		1933	1934	1933	1934	1933	1934		1933	1934	1933	1934	1933	1934		1933	1934	1933	1934	1933	1934		1933	1934	1933	1934	1933	1934
		Feet		*Number*		*Percent*			*Feet*		*Number*		*Percent*			*Feet*		*Number*		*Percent*			*Feet*		*Number*		*Percent*	
American plum								3	8.3	8.2	59	53	59	53														
Birch								19	0	0	0	0	0	0	20	0	0	0	0	0	0	18	9.9	0	1	0	5.9	0
Do								21	8.4	0	19	0	19	0	[2] 22	4.2	0	5	0	5	0							
Total or average									8.4	0	19	0	15.2	0		4.2	0	5	0	4	0		9.9	0	1	0	5.9	0
Boxelder	5	16.4	13.8	175	171	87.5	85.5	2	14.8	12.5	93	91	93	91	10	21.4	21.2	23	23	92	92	18	13.7	2.8	16	14	94.1	82.4
Do	6	14.1	10.6	168	163	84	81.5	3	17.1	14.2	91	91	91	91	11	22.0	21.7	50	50	100	100							
Do								4	13.9	11.5	88	87	88	87	12	21.4	21.0	48	48	96	96							
Do								15	14.6	10.6	185	179	92.5	89.5	14	19.0	16.3	75	75	100	100							
Do								[3] 16	14.0	8.2	160	157	91.4	89.7	20	11.7	2.9	25	12	100	48							
Do								17	15.2	8.4	23	21	92	84	22	14.4	11.9	23	15	92	60							
Do								19	13.5	8.7	50	37	100	74														
Do								21	8.0	5.8	110	97	88	77.6														
Total or average		15.3	12.2	343	334	85.8	83.5		13.8	10.1	800	760	91.4	86.9		19.1	18.0	244	223	97.6	89.2		13.7	2.8	16	14	94.1	82.4
Buffaloberry								19	8.6	8.3	10	9	40	36	20	8.2	8.0	5	5	20	20							
Do								21	10.4	10.3	2	2	8	8	[2] 22	10.1	10.0	27	26	54	52							
Total or average									8.9	8.7	12	11	24	22		9.8	9.7	32	31	42.7	41.3							
Carolina poplar	5	27.1	27.9	16	11	16	11	2	30.5	31.0	2	2	8	8	9	27.4	25.9	4	4	16	16							
Do	6	15.5	13.8	24	7	12	3.5	3	13.8	22.6	17	2	17	2														
Do								4	33.1	33.0	3	3	3	3														
Total or average		20.1	22.4	40	18	13.3	6.0		18.0	28.8	22	7	8.8	2.8		27.4	25.9	4	4	16	16							
Chinese elm								19	22.8	22.9	25	25	100	100	20	24.0	23.7	22	22	88	88	18	24.6	25.0	16	15	94.1	88.2
Do								21	20.2	20.9	23	23	92	92	22	22.1	22.3	23	22	92	88							
Total or average									21.6	21.9	48	48	96	96		23.0	23.0	45	44	90	88		24.6	25.0	16	15	94.1	88.2

See footnotes at end of table.

TABLE 27.—*Average height, number of trees alive, and percentage of survival in 1933 and 1934 of species grown in different spacing distances in 22 shelter-belt combinations at the Northern Great Plains Field Station* [1]—Continued

Species	Spaced 2 by 8 feet							Spaced 4 by 4 feet							Spaced 4 by 8 feet							Spaced 6 by 12 feet						
	Combination no.	Height		Survival				Combination no.	Height		Survival				Combination no.	Height		Survival				Combination no.	Height		Survival			
		1933	1934	1933	1934	1933	1934		1933	1934	1933	1934	1933	1934		1933	1934	1933	1934	1933	1934		1933	1934	1933	1934	1933	1934
		Feet		*Number*		*Percent*			*Feet*		*Number*		*Percent*			*Feet*		*Number*		*Percent*			*Feet*		*Number*		*Percent*	
Chokecherry								2	8.4	7.9	87	84	87	84														
Diamond willow								3	6.5	7.0	14	9	28	18														
Gray birch								1	11.4	0	5	0	3.3	0														
Green ash	5	15.7	16.1	94	89	94	89	1	19.6	18.8	145	142	96.7	94.7	22	18.2	18.4	22	22	88	88	18	17.4	18.9	17	17	100	100
Do	6	12.1	11.5	189	184	94.5	92	2	17.8	17.6	50	50	100	100														
Do								3	16.4	16.4	96	96	96	96														
Do								4	13.6	10.7	93	85	93	85														
Do								7	16.3	16.5	99	98	99	98														
Do								15	13.0	13.1	49	49	98	98														
Do								16	10.5	10.6	25	25	100	100														
Do								17	11.7	12.0	24	24	96	96														
Do								19	11.8	12.0	48	48	96	96														
Do								21	10.9	11.1	69	69	92	92														
Total or average		13.3	13.0	283	273	94.3	91		15.3	14.9	698	686	96.3	94.6		18.2	18.4	22	22	88	88		17.4	18.9	17	17	100	100
Laurel willow	5	10.4	6.0	31	19	31	19	2	0	0	0	0	0	0	8	0	0	0	0	0	0							
Do	6	7.6	0	40	0	20	0	4	13	0	5	0	5	0	9	4.8	0	2	0	8	0							
Do								15	8.7	0	2	0	2	0	10	14.9	3.5	2	1	8	4							
Do								16	0	0	0	0	0	0	11	26.3	26.6	13	12	52	48							
Do								[4] 17	0	0	0	0	0	0	12	19.9	20.6	14	12	56	48							
Do															13	14.5	13.7	10	9	40	36							
Do															14	7.2	0	16	0	32	0							
Total or average		8.8	6.0	71	19	23.7	6.3		11.8	0	7	0	2.2	0		16.1	20.4	57	34	28.5	17.0							
Northwest poplar								19	25.3	0	2	0	8	0	22	19.3	0	3	0	12	0	18	25.5	0	1	0	5.9	0
Do								21	20.3	20.3	17	4	34	8														
Total or average									20.8	20.3	19	4	25.3	5.3		19.3	0	3	0	12	0		25.5	0	1	0	5.9	0

Norway poplar																10	33.1	29.6	13	13	52	52								
Poplar								15	0	0	0	0	0	0	11	35.4	36.7	7	7	28	28								
Do								16	0	0	0	0	0	0	12	32.8	30.9	17	17	34	34								
Do															13	22.1	18.1	25	13	33.3	17.3								
Do															14	22.0	18.6	12	4	12	4								
Total or average									0	0	0	0	0	0		26.6	26.6	61	41	24.4	16.4								
Red willow								21	10.5	0	2	0	4	0	22	0	0	0	0	0	0								
Russian golden willow	5	12.5	5.9	19	12	19	12	2	0	0	0	0	0	0	11	33.5	20.8	20	17	80	68								
Do								3	10.0	6.9	46	5	46	5	12	26.3	28.9	19	15	76	60								
Do								7	0	0	0	0	0	0	13	12.2	7.1	20	6	26.7	8								
Do								16	0	0	0	0	0	0	14	0	0	0	0	0	0								
Total or average		12.5	5.9	19	12	19	12		10.0	6.9	46	5	16.7	1.8		20.6	21.8	59	38	39.3	25.3								
Sharpleaf willow								19	15.8	12.2	3	2	6	4	20	6.9	0	3	0	12	0	18	13.1	15.0	8	2	47.1	11.8	
Do								21	9.1	8.4	23	6	46	12	22	0	0	0	0	0	0								
Total or average									9.9	9.4	26	8	26	8		6.9	0	3	0	6	0		13.1	15.0	8	2	47.1	11.8	
Siberian pea-tree	5	10.5	10.7	174	167	87	83.5	4	9.4	9.4	84	83	84	83	8	10.4	10.5	21	21	84	84								
Do	6	10.8	11.0	159	153	79.5	76.5	[4] 17	8.9	8.9	40	40	80	80	9	10.4	10.7	24	24	96	96								
Do															10	10.4	10.7	24	23	96	92								
Do															13	10.1	10.1	24	24	96	96								
Total or average		10.6	10.8	333	320	83.2	80		9.2	9.2	124	123	82.7	82.0		10.3	10.5	93	92	93	92								

[1] The height of each species in each combination and the average height of each species in all combinations are the averages of all surviving trees. The percentage of survival of each species is the actual percentage based on the total number of trees originally planted.

[2] Trees spaced 2 by 8 in 4 by 8 combination.

[3] 2 rows 2 by 4; 3 rows 4 by 4.

[4] Trees spaced 2 by 4 in 4 by 4 combination.

The following species occur in one combination and spacing distance only: American plum, chokecherry, diamond willow, gray birch, and Norway poplar. The survival of American plum has been influenced by the species in the adjacent rows. Plum trees in rows 1 and 2 of combination 3 were badly suppressed by the boxelder in row 3, which resulted in the stand at the end of 1933 being reduced to 60 and 16 percent, respectively, as compared with stands of 76 and 84 percent for rows 21 and 22, respectively, which are free from the boxelder influence.

American plum and chokecherry showed no serious killing back as a result of the drought conditions during 1934, but suffered loss of a few trees. Diamond willow showed a reduction in stand from 14 to 9 trees in 1934; surviving trees are chiefly sprout growth. Gray birch became a complete loss during 1934 with the death of the last 5 trees in combination 1. Norway poplar killed back considerably, but suffered no reduction in stand. This species was planted in combination 10 only, which together with combinations 11 and 12 have a more favorable site than the other combinations. This has undoubtedly influenced the survival of this species to a considerable extent. This species planted in other tests not discussed in this bulletin became completely eliminated in 1934.

The other species used in these combinations occur in two or more spacing distances. Of these species the following are governed more in their reactions by the inherent qualities of the species themselves than by the differences in spacing distances or type of combination employed: Birch species, Carolina poplar, laurel willow, Northwest poplar, poplar species, red willow, Russian golden willow, and sharpleaf willow. Diamond willow, gray birch, and Norway poplar, which occur in one spacing distance only, are included in this group for discussion purposes. Heavy killing back and reduction in stand have been quite prevalent in all these species throughout the period, and they cannot be recommended for future planting on the average upland site. The data, however, do show that laurel willow, Russian golden willow, and Norway poplar are suitable for planting on sites which collect a certain amount of run-off moisture during the year. Combinations 10, 11, and 12 are located in a small depression, and the beneficial influences of this site are reflected in the growth and survival of the two willow species in comparison with similar data for other combinations on less favorable sites.

Boxelder was planted in single and double rows in spacing distances of 2 by 8 feet; in single, double, and quadruple rows in distances of 4 by 4 feet; in single rows in distances of 4 by 8 feet; and in 1 single row in distances of 6 by 12 feet. A comparison of the growth data for the different spacing distances shows decidedly the best average growth in the distance of 4 by 8 feet. Combinations 10, 11, and 12 occur in this particular distance, and the effects of the favorable site are very clearly reflected in the growth of boxelder in these particular combinations. Killing back during 1934 occurred in all combinations in all spacing distances, the most severe being in combination 20, spaced 4 by 8 feet, and in combination 18, spaced 6 by 12 feet. All trees in these two combinations were killed to the ground. In the former combination, boxelder is in row 2 with only 5 trees surviving in row 1. In the latter combination, boxelder is in row 1 bordering on a 24-foot cultivated alley. These wider distances have

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evidently subjected the soil and trees to more extreme drying during the drought period than that which has occurred in the closer distances in which boxelder was planted in interior rows. Survival is good and differs little in all distances and combinations, except in combination 20, in which a 52 percent loss occurred during 1934. All trees in combination 18, spaced 6 by 12 feet, were in extremely weak condition at the close of the year, the live portion being confined to weak shoot growth from the base.

The planting of boxelder in single rows alternated with other species appears the most desirable method for this species. A distance of 4 by 8 feet is preferable for the species, owing to its spreading growth characteristics.

The data for buffaloberry show very poor survivals in 1933 and 1934 for all spacing distances. As shown in tables 23, 24, 25, and 26, only a low percentage of trees became established during the initial years of planting. This will be discussed more fully under Survival of Species. The species was planted in outside rows in all combinations and has been subjected to side crowding by boxelder or willow species, except in combination 22 in which the adjacent willow row shows a complete loss after 1926. Buffaloberry trees in this combination were spaced 2 feet apart in the row and show an average growth practically as great as that of the trees in the other combinations with wider spacing distances. Trees planted 2 feet apart in the row make a more desirable hedge for wind and snow protection than trees planted 4 feet apart. A distance of 8 feet between rows is desirable if competitive species are planted in adjacent rows.

Chinese elm has made somewhat the best growth in the widest spacing distance of 6 by 12 feet in the 1 combination where thus grown, as compared with its growth in 2 combinations at each of the other lesser distances. No individual combination with the other distances equals its height at the widest distance. Survivals are highest in the distance of 4 by 4 feet, and the 2 losses occurring during the severe drought of 1934 were in the 2 widest distances. This species makes the most rapid and tallest growth of any of the species which have maintained satisfactory survivals. It can be safely used in the interior rows of shelter belts without danger of suppression by other species.

Green ash was planted in all 4 spacing distances, but in only 1 combination and 1 row each at the 2 widest distances and in 2 combinations with 2 and 4 rows each at the closest as compared with the 10 combinations in which it is spaced 4 by 4 feet, most of which have 2 or more rows in various groupings. The maximum growth of this species has been made where it has had the most room, at spacings of 6 by 12 feet, 4 by 8 feet, and in combination 1, spaced 4 by 4 feet. This particular combination was originally planted to alternate rows of gray birch and green ash. The birch did not establish a full stand, and the surviving trees gradually became eliminated until 1934, when the combination became a pure stand of green ash spaced 4 by 8 feet through the elimination of the last 5 trees in row 1.

Survival of green ash is good in all spacing distances, and only minor losses occurred during 1934.

Green ash trees planted in double rows in combination 2, spaced 4 by 4 feet, have done much better than those in quadruple rows in

combination 4 of the same spacing distance. Trees in this latter combination suffered the most severe killing back and heaviest losses which occurred during 1934 in any of the combinations with all spacing distances. Considerable variation in growth occurs in spacing distances of 4 by 4 feet when the species is planted in single rows between other species. Examples of these differences may be found in the average heights of single rows in combinations 3, 15, 16, and 21 in which boxelder occurs as the adjacent species on either side in all combinations. The data tend to indicate that it is desirable to plant green ash in double rows if spacing distances of 4 by 4 feet are used, as is evidenced by combination 2. This will prevent possible suppression by faster growing species in adjacent rows. The species does remarkably well in several adjacent rows when spaced 4 by 8 feet, as shown by the data for combinations 1 and 7 originally spaced 4 by 4 feet but now pure plantings of green ash spaced 4 by 8 feet through the death of all trees in adjacent rows.

Figure 7 shows the growth of green ash in combination 1, originally spaced 4 by 4 feet, which later became a planting spaced 4 by 8 feet owing to the loss of the species in the alternate rows, and in combination 18 which has always been spaced 6 by 12 feet. The latter combination was planted 2 years later than the former, but the difference in growth is due to factors other than the difference in time of planting.

Differences between the average growth and survival of green ash in distances of 4 by 8 and 6 by 12 feet are not sufficient to recommend the use of either specific distance. The species will maintain satisfactory growth and survival in all distances if it is properly placed in the planting in relation to other species. A distance of 4 by 8 feet results in the development of better tree form than the closer distance of 2 by 8 or 4 by 4 feet.

Siberian pea-tree was planted in single or double outside rows in 8 combinations with 4 different spacing distances. It has done best with a distance wider than 4 feet between rows. Suppression by faster growing adjacent species has been quite common in distances of 4 feet between rows. Growth has been very uniform in all combinations within a given spacing distance. Survival averages best with 4 by 8 feet spacing but is generally good in all distances. A distance of 8 feet between rows is recommended for this species. From the standpoint of the desirability of having a dense hedge for outside rows, a distance of 2 feet apart in the row is recommended for all outside rows. Second rows of this species may well be planted 4 feet apart in the row, to prevent possible suppression and loss caused by trees within the rows.

SURVIVAL OF SPECIES

The survival data given in tables 5 to 26 show low survivals in 1934 for certain species, but some of these species had poor stands when the first data were recorded in 1917. For the purpose of making a more accurate comparison of the ability of the different species to survive the prevailing climatic and other local conditions, it is assumed that losses occurring prior to the end of the 1918 growing season (the time when data for the year were recorded) were planting losses

FIGURE 7.—Comparison of growth of green ash: *A*, Combination 1, planted in 1915 and spaced 4 by 4 feet. *B*, Combination 18, planted in 1917 and spaced 6 by 12 feet, in which the green ash (center row) has been spaced 6 by 12 feet since the year of planting. Combination 1 later became an almost pure planting of green ash spaced 4 by 8 feet through the mortality of species in adjacent rows; Northern Great Plains Field Station.

which are not an indication of hardiness. These losses, however, may tend to show the ease or difficulty of establishing the various species. Losses occurring after the end of the 1918 growing season are due to factors other than planting losses and are indicative of the ability of the species to survive in its local environment. The 22 combinations were planted during the years 1915, 1916, and 1917, losses being replaced the first year after planting only. Trees surviving in 1934, therefore, vary in age from 17 to 19 years.

The number of trees planted; the number alive in the fall of 1918, 1923, 1928, 1933, and 1934; the percentage of the 1918 stand alive in 1923, 1928, 1933, and 1934; and the percentage of the planted trees

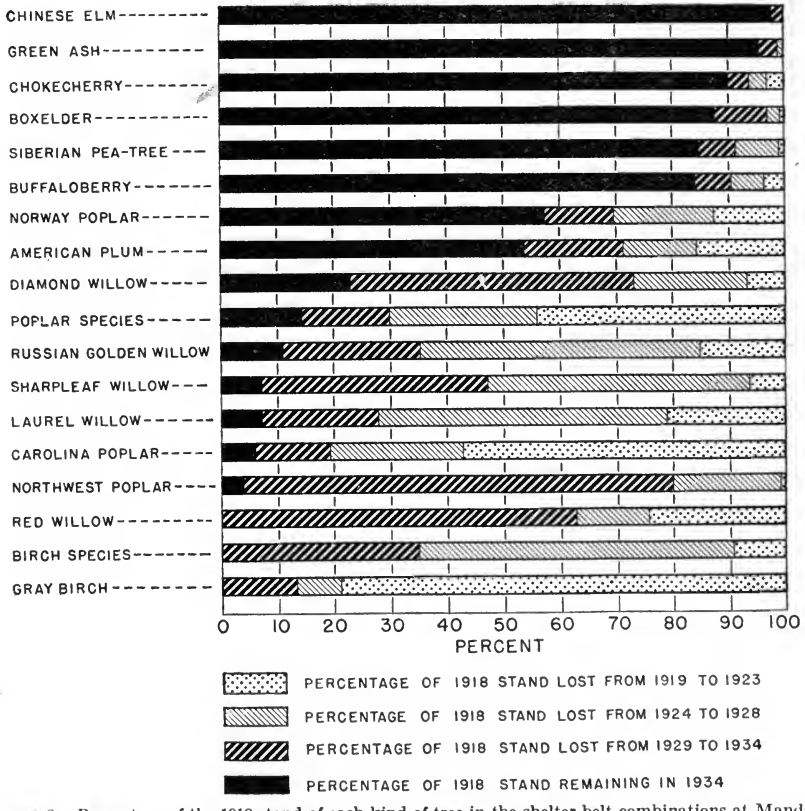

FIGURE 8.—Percentage of the 1918 stand of each kind of tree in the shelter-belt combinations at Mandan lost from 1919 to 1923, lost from 1924 to 1928, lost from 1929 to 1934, and surviving in 1934.

alive in 1918 and 1934 of each species in the 22 shelter-belt combinations are given in table 28.

The percentage of the 1918 stand of each kind of tree in the shelter-belt combinations at Mandan lost from 1919 to 1923, lost from 1924 to 1928, lost from 1929 to 1934, and remaining alive in 1934 is shown in figure 8.

TABLE 28.—*Number of trees planted, the number alive in 1918, 1923, 1928, 1933, and 1934, the percentage of the 1918 stand alive in 1923, 1928, 1933, and 1934, and the percentage of the original planting alive in 1918 and 1934 of each species in the 22 shelter-belt combinations grown at the Northern Great Plains Field Station*

Species	Trees planted [1]	Trees alive [2] in—					Trees of 1918 stand alive in—				Planted trees alive in—	
		1918	1923	1928	1933	1934	1923	1928	1933	1934	1918	1934
	Number	*Number*	*Number*	*Number*	*Number*	*Number*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Chinese elm	117	110	110	110	109	107	100	100	99.1	97.3	94	91.5
Green ash	1,067	1,047	1,047	1,035	1,020	998	100	98.9	97.4	95.3	98.1	93.5
Chokecherry	100	94	91	88	87	84	96.8	93.6	92.6	89.4	94	84
Boxelder	1,542	1,525	1,520	1,473	1,403	1,331	99.7	96.6	92	87.3	98.9	86.3
Siberian pea-tree	650	632	627	575	550	535	99.2	91	87	84.7	97.2	82.3
Buffaloberry	125	50	48	45	44	42	96	90	88	84	40	33.6
Norway poplar	25	23	20	16	13	13	87	69.6	56.5	56.5	92	52
American plum	100	100	84	71	59	53	84	71	59	53	100	53
Diamond willow	50	40	37	29	14	9	92.5	72.5	35	22.5	80	18
Poplar	375	285	159	85	61	41	55.8	29.8	21.4	14.4	76	10.9
Russian golden willow	525	514	433	179	124	55	84.2	34.8	24.1	10.7	97.9	10.5
Sharpleaf willow	167	143	133	67	37	10	93	46.9	25.9	7	85.6	6
Laurel willow	825	772	607	214	135	53	78.6	27.7	17.5	6.9	93.6	6.4
Carolina poplar	575	519	221	98	66	27	42.6	18.9	12.7	5.2	90.3	4.7
Northwest poplar	117	108	107	86	23	4	99.1	79.6	21.3	3.7	92.3	3.4
Red willow	75	8	6	5	2	0	75	62.5	25	0	10.7	0
Birch	267	110	99	38	25	0	90	34.5	22.7	0	41.2	0
Gray birch	150	77	16	10	5	0	20.8	13	6.5	0	51.3	0

[1] The number of trees originally planted is not increased by replacements.
[2] Data recorded at end of growing season of year given.

The number of trees alive in 1918 represent the number going into 1919. The periods from then on, to and including 1923, 1928, and 1934, are 5-, 10-, and 16-year periods for which percentage survivals are shown. The periods ended in 1923 and 1928 have been included to give an indication of how the losses have been distributed through the 16-year period 1919–34. Data for the year 1933 have again been included for comparison purposes with those of 1934, to show the effects of the severe drought during the latter year. It will be noted that certain species suffered only minor losses during 1934, whereas other species suffered losses varying up to 100 percent of the 1933 stand. The species are arranged in order of survival in 1934 for the 16-year period.

Chinese elm, green ash, chokecherry, boxelder, Siberian pea-tree, and buffaloberry show survivals at the end of the 16-year period of 84 percent or more of the trees which had become established in 1918. This percentage survival is considered satisfactory for the period involved. The survival data for buffaloberry in 1934 show 84 percent of the 1918 stand and 33.6 percent of the number of planted trees. This indicates considerable difficulty in establishing the stand for this species. Stands of 82.3 to 93.5 percent of the number of trees planted of the other five species survived in 1934.

Norway poplar suffered no losses during 1934 and has a considerably larger percentage survival than any of the other poplar species. The data, however, are limited to a very small number of trees in one combination only. This combination has a more favorable site than the majority of other combinations, which is undoubtedly responsible for the high survival shown in comparison with survivals of other poplar species and with survivals of the same species in other test plantings on the Mandan station not discussed in this bulletin. The species cannot be recommended except for planting on sites favorably situated in relation to moisture.

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American plum shows a 47-percent loss during the 16-year period 1919–34. These losses have been distributed throughout the entire period and are due primarily to suppression by boxelder in a row adjacent to two of the plum rows. The plum was planted in rows 1, 2, 21, and 22 in combination 3, spaced 4 by 4 feet. Boxelder was planted in row 3. Survivals in rows 1 and 2 in 1934 are 44 and 16 percent, respectively, as compared with survivals of 72 and 80 percent in rows 21 and 22, respectively. The survivals in the two latter rows are such that the species can be recommended for planting in farm shelter belts provided competitive species are not planted in adjacent rows.

Several of the remaining species show good percentage survivals of the 1918 stand at the end of the first 5-year period. Of these species Northwest poplar is the only one maintaining a satisfactory survival at the end of 10 years. This species became practically eliminated at the end of 16 years. This species meets the need for a temporary tree of fast-growing habits where such is desired.

Of the 18 species used in the 22 shelter-belt combinations, 6 species only have maintained satisfactory stands for a minimum period of 16 years, including 1934, a year of severe drought. These are Chinese elm, green ash, chokecherry, boxelder, Siberian pea-tree, and buffaloberry. American plum may be included if planted in rows adjacent to species without spreading, side-branching characteristics. Many trees of several of these species actually have been growing for a period of 20 years, the first plantings having been made in 1915. Survivals of other species are generally low at the end of 10-year and 16-year periods.

Survival for 16 years in these tests may fairly be assumed to indicate the ability of a species to survive the environmental conditions and to warrant the inclusion of these 6 or 7 species in shelter belts in the northern Great Plains under dry-land conditions.

CONCLUSIONS AND RECOMMENDATIONS

SPECIES SUITABLE FOR SHELTER BELTS

The prevailing climatic conditions on the Mandan station are, in general, representative of the prevailing climatic conditions found in the northern Great Plains. Chinese elm, green ash, chokecherry, boxelder, Siberian pea-tree, buffaloberry, and possibly American plum are the only broadleaf species which have shown evidence that would warrant their future use in shelter belts when planted in spacing distances of 2 by 4, 4 by 4, 4 by 8, and 6 by 12 feet. It does not necessarily follow that the above-mentioned species are the only ones suitable for this purpose. They are, however, the only species found suitable out of the 18 species or varieties that were used in the 22 shelter-belt combination tests under discussion.

ARRANGEMENT OF SPECIES IN SHELTER BELTS

The primary object of planting a shelter belt is to protect farm buildings, orchards, gardens, and farm crops against high winds and drifting snow. Any body of trees that gives this protection may be called a shelter belt or windbreak. Its protective influences are purely mechanical, and its effectiveness therefore depends entirely on the degree of penetration by wind currents and the growth contours of the belt to divert the air currents upward and relieve the horizontal wind pressure.

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The arrangement of tree species within the belt will therefore govern the effectiveness for maximum wind and snow protection. This arrangement will also have an important influence on determining whether the maximum growth of species will be maintained or whether certain species will eventually be suppressed. The ultimate height attained by the trees will govern the distance for which wind protection will be afforded. Bates (*3*) found:

> The area protected is proportional to the height and density of the windbreak, and the distance to which protection is felt increases with wind velocity. The protection is appreciable for a distance equal to 5 times the height in the windward direction and 15 or 20 times the height leeward.

Cheyney (*4*), in a study of shelter belts in the prairie sections of Minnesota, found the wind velocity reduced on the leeward side of the shelter belt for a distance of at least 10 tree heights. The arrangement of tree species and the spacing distances used in the shelter belt should therefore be such that will favor maximum growth, density, and survival if the belt is to form an effective barrier against winds and drifting snow.

If the belt is to give this maximum protection, a low-growing bushy-type species should be planted in outside rows. This is particularly necessary on the side of the prevailing winds, as the bushy species will tend to break and diffuse the direct wind current near the ground level. A tall-growing species, comparatively free of lower side branches, in such position would allow the wind to pass into the interior of the belt with very little obstruction. Taller-growing species should be placed in the interior rows in such position that the species making the tallest growth will occupy the center rows of the belt. A cross section of a shelter belt planted in this manner will, after a few years' growth, resemble an inverted V. This arrangement will deflect the air currents upward from the low-growing species on the outside to the tallest species in the center rows of the belt. The air current at that point will then continue upward for some distance, leaving an area on the leeward side of the belt comparatively free of wind. The deflection and diffusion reduces the carrying capacity of the wind, which results in any carried snow being deposited in the interior of the belt. The varying branching habits of the different species in interior rows will tend to diffuse the air currents that pass into the interior of the belt. These branches will also assist in the development of shade to prevent excessive growth of weeds and drying out of soil moisture.

An arrangement such as previously mentioned is favorable for the growth of each of the species. Low-growing species will never become completely overtopped and suppressed as a taller-growing species occurs only on one side.

Siberian pea-tree, buffaloberry, chokecherry, and American plum are all comparatively low-growing species suitable for outside rows. The two former species should be cut back to make heavy side branching near the base. The two latter species sucker profusely from the roots and will quickly form a dense hedge if the suckers are allowed to remain. It is advisable to keep down any suckers which may appear between rows, otherwise they will eventually spread and become a detriment to the interior trees.

Green ash, boxelder, and Chinese elm are suitable for interior rows, planted in the order named. Green ash develops very few spreading side branches, and there is very little danger of this species suppressing

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the lower-growing hedge species in the outside row. Boxelder and, to a less extent, Chinese elm develop heavy side branches which

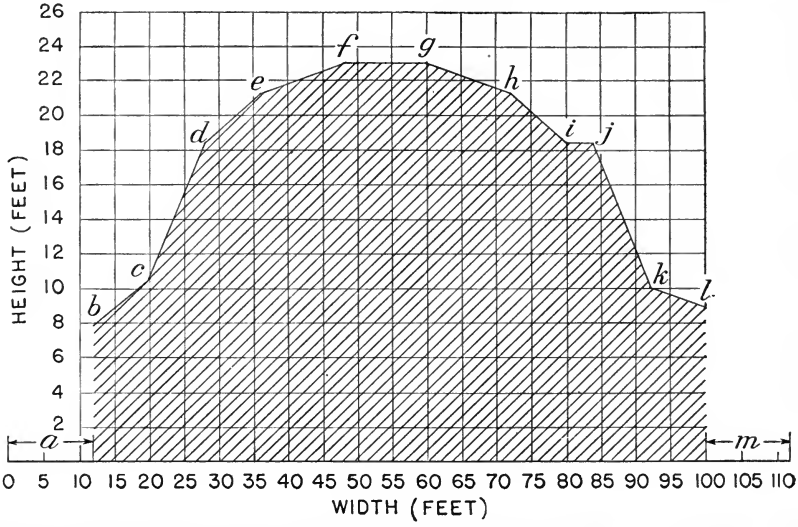

FIGURE 9.—Planting plan, showing arrangement of species and spacing distances for an effective shelter belt. Height data taken from the spacing distance of 4 by 8 feet in table 26. (*a*) and (*m*) indicate minimum width of 12 feet of cultivated land outside first and last rows of trees; (*b*) chokecherry, spaced 2 by 8 feet; (*c*) Siberian pea-tree spaced 2 by 8 feet; (*d*) green ash spaced 4 by 8 feet; (*e*) boxelder spaced 4 by 8 feet; (*f*) and (*g*) Chinese elm spaced 6 by 12 feet; (*h*) boxelder spaced 4 by 8 feet; (*i*) and (*j*) green ash spaced 4 by 4 feet; (*k*) buffaloberry spaced 4 by 8 feet; (*l*) American plum spaced 4 by 8 feet.

will materially help in diffusing the wind and in forming the dense overhead shade necessary to prevent weed growth. The Chinese elm will also give the height growth necessary for long-distance protection. Other hardy species not tried in these experiments will occupy positions in the belt based upon their growth characteristics.

A cross section of a shelter belt planted according to the arrangement just discussed is shown in figure 9. The height data used in this figure for the different species are taken from the spacing distance of 4 by 8 feet in table 26.

WIDTH OF SHELTER BELTS

The series of 22 shelter belts under discussion have not yielded satisfactory data on the number of rows needed for an effective shelter belt. As shown in figure 1, the 22 combinations were all planted adjacent to each other, the rows running north and south. Each combination has therefore tended to protect the one immediately to the east from the prevailing northwest winter winds. Observations have been made during the winter months, however, of two shelter belts on the Mandan station which were planted for orchard-protection purposes. These belts are located on a gentle north slope on a site severely exposed to the northwest winter winds. The belts were planted to buffaloberry in pure stand, spaced 4 by 4 feet, the rows running north and south. One belt consists of 11 rows of trees and the other belt of 4 rows of trees, the two belts being a straight continuation, except for a cultivated roadway of 24 feet between belts.

A very dense growth from the ground up has developed in both belts, which has been aided by reproduction of several tree and shrub species from seeds carried in by birds. The trees have an average

height of approximately 12 feet. Drifting snow is carried through the belt of 4 rows and lodges for a distance up to 30 feet on the leeward side of the belt. The belt of 11 rows holds all the snow in the interior rows with no evidence of drifting on the leeward side. It would, therefore, appear desirable to have a minimum of 11 rows of trees for farm-building protection on very exposed sites, if buildings, yards, and feed lots are to be kept free of drifting snow. For less exposed sites, 6 or 8 rows may be sufficient. For orchard or garden protection, where drifting snow may be a desirable feature through the benefits of covering tender plants and the additional resultant moisture, a maximum of 4 rows would probably be sufficient.

SPACING DISTANCES FOR SHELTER BELTS

The ultimate aim in the selection of a spacing distance is to so space the trees that the maximum growth and survival may be maintained and to develop within the shelter belt as nearly as possible a natural forest condition.

Data that have been presented show that the growth habits of the species in an adjacent row govern to a large extent the distance that should be used between rows for the different species. Some species will make better growth in a given spacing distance when planted in double rows than when planted in single rows between faster-growing species.

Siberian pea-tree and buffaloberry will maintain satisfactory growth when planted in spacing distances of 2 by 8 or 4 by 8 feet. The former distance is helpful in the development of a dense hedge near the base, which is necessary for wind and snow protection. American plum and chokecherry data are limited to spacing distances of 4 by 4 feet. Their habits of growth, however, indicate the use of a spacing distance of 2 by 8 feet for outside rows on the windward side and a distance of 4 by 8 feet for outside rows on the leeward side of the belt.

Green ash will grow satisfactorily in a spacing distance of 4 by 4 feet when planted in two adjacent rows and in a distance of 4 by 8 feet when planted in single rows between faster growing species.

Boxelder shows a preference for spacing distances of 4 by 8 feet, although satisfactory growth and survival have been maintained in spacing distances of 2 by 8 and 4 by 4 feet. A distance of 6 by 12 feet appears detrimental to the growth of this species.

Chinese elm definitely appears to favor a distance of 6 by 12 feet, although satisfactory growth and survival have been maintained in distances of 4 by 4 and 4 by 8 feet. Very little side branching has occurred in the spacing distance of 4 by 4 feet. This is somewhat of a detriment, as side branches diffuse the wind entering the belt and help the development of shade for preventing undergrowth.

The spacing distances recommended will favor maximum growth and survival, resulting in satisfactory wind and snow protection; and they are such that in a comparatively few years the trees will have developed the necessary overhead shade that will result in the floor of the belt approaching natural forest conditions. That this latter feature can be accomplished has been definitely proved in Siberian pea-tree, chokecherry, American plum, green ash, and boxelder sections spaced 2 by 8, 4 by 4, and 4 by 8 feet of the combinations under discussion. A heavy leaf mulch has covered the ground in

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these sections, and there has been no type of undergrowth in them since 1922. That this condition cannot be attained in wide spacing distances and in sections where heavy losses open up the stand has been demonstrated in the spacing distances of 6 by 12 feet and in the poplar and willow sections. The wind blows all fallen leaves out of these sections, and constant cultivation and hoeing are necessary to prevent excessive weed growth.

Wide differences of opinion prevail on the question of spacing trees for shelter belts on the northern Plains. Most of the opinions advanced on this subject are in favor of wide planting, probably the use of wider distances than any of those used in this series of tests. Many recommendations are based more on theory than on actual fact, the assumption being advanced that the drier the area the more room the trees need to survive. The recommendations of spacing distances based on actual data are generally in favor of closer distances. Ross (*11*) recommends a spacing distance of 4 by 4 feet for the Prairie Provinces of Canada, stating that the success of this distance has been proved beyond question as being the most suitable for that area. Jensen and Harrington (*7*) recommend a distance of 4 to 6 feet between trees in the row and rows 10 to 12 feet apart. They seriously question the advisability of placing rows 16 feet apart to accommodate wide cultivating machinery. Harrington and Morgan (*6*) recommend the use of a wider distance than 4 by 4 or 4 by 8 feet. Cheyney (*4*) recommends that trees originally planted 2 by 4 or 4 by 6 or 8 feet be thinned to 10 or 15 feet apart at 25 years of age.

The possibilities of stimulating growth by thinning closely planted shelter belts at some time in the future appears a very logical conclusion. The time at which this thinning should take place, however, requires careful investigation. Very few favorable effects are noticeable on the successful species in the shelter-belt combinations under discussion as a result of increased spacing distance through complete mortality of species in adjacent rows.

Combination 1 was originally planted to alternate rows of green ash and gray birch and combination 7 to alternate rows of green ash and Russian golden willow. Both combinations were spaced 4 by 4 feet. The two combinations are now pure plantings of green ash spaced 4 by 8 feet through the loss of birch and willow species in alternate rows. No noticeable stimulation in the growth rate of green ash in either combination has occurred since the spacing distance was increased. The effects of the thinning, however, will doubtlessly become more significant as the age of the stand increases.

Chinese elm is favored by the widest spacing distance used in this series of tests and also illustrates the effects of thinning at a period up to 17 years of age. This particular species was planted in 1917 in combination 19, spaced 4 by 4 feet. Survival of species in adjacent rows was 96 percent in 1925, 96 and 40 percent in 1930, and 96 and 0 percent in 1934. Chinese elm was also planted in 1917 in combination 22, spaced 4 by 8 feet. The adjacent species on one side was the same as in combination 19; and birch, a less competitive species, was substituted for green ash on the other side. Survival of adjacent species was 88 and 16 percent in 1925, 88 and 0 percent in 1926, 56 and 0 percent in 1930, and 0 percent in 1934. This has given Chinese elm a spacing distance of 16 feet on one side for the last 9 years and considerably reduced root competition for the past

several years within a distance of 16 feet on the other side. At the end of 1934 the average height and survival of Chinese elm were 22.9 feet and 100 percent in combination 19 as compared with 22.3 feet and 88 percent in combination 22. One tree died in the latter combination during 1934. The thinning which has taken place in the latter combination has had no beneficial influences on growth and survival at the present age of the stand. Thinning may have beneficial effects at some future time. There is, however, little or no evidence to recommend such thinning at the present age of the trees except in cases where trees have become badly suppressed, as in the case of green ash in combination 15.

SUMMARY

Investigations were commenced at the Northern Great Plains Field Station, Mandan, N. Dak., in 1913 to determine the possibilities of growing trees on the northern Great Plains which would provide shelter to farm buildings, orchards, and gardens.

Early settlers had planted trees for protection purposes with only limited success.

A series of 22 shelter-belt combinations were planted on the Mandan station during the years of 1915, 1916, and 1917 to obtain data on spacing distances, height growth, survival, adaptability, and congeniality of species, the most suitable trees for outside rows, and the optimum width of shelter belts. The trees were planted and have been grown strictly under dry-land conditions.

Climatic conditions on the Mandan station are characterized by extremes of temperature, limited precipitation, high winds, and a high evaporation rate.

The average annual precipitation for the 20-year period 1915–34 is 14.99 inches. Ten of the 20 years had an annual precipitation below the average for the period, and 5 of them were the 5 driest consecutive years on record for the 60-year period 1875–1934.

Extremes of temperature during the 20-year period ranged from 110° to −43° F. The average seasonal evaporation during the same period was 34.474 inches, and the average wind velocity was 6 miles per hour.

Eighteen tree species were used in the 22 combination tests. Spacing distances used were 2 by 8, 4 by 4, 4 by 8, and 6 by 12 feet. Arrangement of species and the number of rows differed in the various combinations.

All poplar, willow, and birch species show heavy killing-back and heavy mortality throughout the period. Other species show evidences of killing-back in occasional years.

Seven species only have maintained satisfactory growth and survival. They are Chinese elm, green ash, boxelder, chokecherry, Siberian pea-tree, buffaloberry, and American plum.

Hedge species have been more or less suppressed by side branches of boxelder when planted in rows adjacent to that species. Green ash does not develop spreading side branches and is more suitable for planting adjacent to the hedge species.

The choice of a spacing distance should be such that maximum growth and survival will be maintained and overhead shade developed eventually to approach natural forest conditions in the belt. The growth habits of species in an adjacent row will govern to a large

extent the distance between rows. A cross section of a properly arranged shelter belt will resemble an inverted V. This is accomplished by placing low-growing species in outside rows and taller growing species in the center rows. This arrangement gives maximum wind protection, favors growth and survival, and aids in the development of shade to suppress weed growth and in the development of natural forest conditions.

A minimum of 6 or 8 rows of trees are needed for farm-building protection. On severely exposed sites this number should be increased to 11 rows. Four rows of trees are the maximum needed for orchard or garden protection.

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ALFALFA EXPERIMENTS AT STONEVILLE, MISS.

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(The Bureau of Plant Industry in Cooperation with the Mississippi State College and Agricultural Experiment Station)

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INTRODUCTION

In the lower Misssissippi Delta, in the States of Mississippi, Arkansas, and Louisiana, a large percentage of the clay soils that are naturally well drained or else have been drained artificially are well adapted to alfalfa. From time to time failures due to unknown causes have been reported where the crop previously had been grown satisfactorily. The situation became particularly serious in 1928, and the demand for assistance in determining the cause of the failures resulted in a congressional appropriation in 1929. Under this appropriation, the Division of Forage Crops and Diseases of the Bureau of Plant Industry, in cooperation with the Mississippi Agricultural Experiment Station, inaugurated in that same year a series of experiments at Stoneville, Miss., to ascertain if possible the cause of the trouble and to suggest remedies. The results of these investigations are reported in detail in this bulletin and indicate that while some of the failures can be attributed to the use of seed of unadapted varieties, failure to cut at the proper stage of growth, to poor preparation of the seed bed, and to insect and disease injury, the most important factor in the successful production of alfalfa is adequate surface drainage.

[1]Acknowledgments are made to W. E. Ayres, of the Delta Experiment Station, at Stoneville, Miss., for assistance in planning these investigations, and to C. B. Haddon for data furnished from cooperative experiments at the Northeast Louisiana Experiment Station, at St. Joseph.

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ALFALFA SOILS OF THE MISSISSIPPI DELTA

During the winter of 1929–30, a brief survey was made of the soils of the Yazoo-Mississippi Delta for the purpose of determining the relation of soil type to the growth of alfalfa.[2] It was estimated that 90 percent of the alfalfa acreage in the Mississippi Delta is on soils of the Sharkey series, the most extensive type in this series being Sharkey clay, commonly known to Delta planters as "heavy buckshot." Sharkey clay is characterized as having a dark-colored surface soil underlain by a more or less mottled light-drab to bluish-gray stiff clay. Two phases are recognized, one occupying broad, flat, poorly drained basins and the other a better-drained phase, occurring as low ridges or as areas having a billowy relief. The former, which is by far the more extensive, is neutral to slightly acid in reaction. Near the river the "high position" Sharkey clay is usually only slightly acid and is well adapted to alfalfa. At most distances greater than 15 miles from the river this soil becomes more and more acid and is not suitable for alfalfa production.

Alfalfa is also grown to a limited extent on soils of the Sarpy series. These soils are usually more acid than the Sharkey soils, are inclined to be droughty, and as they are good cotton soils only a small percentage of the alfalfa is grown on them. Alfalfa is as productive for 2 to 3 years on Sarpy clay or clay loam that is not too acid as it is on Sharkey clay, but stands survive longer on the Sharkey soils.

VARIETAL TESTS

When the cooperative alfalfa investigations were started at Stoneville there were evidences that in some instances the use of unadapted nonhardy varieties in the northern part of the Delta in Mississippi and Arkansas was responsible for failures due to winter-killing, or else the stand was thinned out to such an extent that grass and weeds lowered the yield and quality of the hay produced. Also as a relatively large amount of northern-grown common alfalfa seed was being sold in the Delta at prices higher than seed of Kansas or Utah common, there was some question as to whether or not the purchase of seed of these more hardy strains was economical. To obtain definite information on these points the alfalfa variety tests have included varieties and strains having a wide range of adaptability and varying in hardiness from tender varieties such as India and Hairy Peruvian through the intermediate types to the hardy variegated alfalfas.

The first test, sown March 7, 1930, included 21 varieties and strains of alfalfa, each being repeated three times, with every fifth plot a check of Utah Common. The results are given in table 1. In this test the higher yielding strains belong to the southern common group of alfalfas, which can be explained in part by the fact that the winters of 1930–31 and 1931–32 were so mild that very little winter-killing occurred in any of the varieties. In subsequent trials, one sown in the fall of 1932 and another in the fall of 1933, the southern common alfalfas were either winter-killed or were injured

[2] HENDRICKSON, B. H. PRELIMINARY REPORT: RECONNAISSANCE OF SOILS OF YAZOO-MISSISSIPPI DELTA WITH SPECIAL REFERENCE TO ALFALFA GROWING. U. S. Dept. Agr., Bur. Chem. and Soils. 1930. (Unpublished.)

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by the colder winters of 1932–33 and 1933–34 to such an extent that they yielded less than most of the hardier varieties and strains.

TABLE 1.—*Annual and average yields of hay on a 12-percent moisture basis and percentage of check of several varieties and strains of alfalfa sown at Stoneville, Miss., Mar. 7, 1930*

Variety	Accession no.[1]	Acre yield					Percentage of check
		1930 [2]	1931	1932	1933	Average	
		Pounds	*Pounds*	*Pounds*	*Pounds*	*Pounds*	
Argentine	F. C. 15996	2,506	10,934	10,508	7,397	9,613	110.6
Italian	F. C. 15657	2,289	10,675	10,075	7,318	9,356	107.7
South African	F. C. 14204	2,188	11,615	10,508	5,618	9,247	106.4
Argentine	F. C. 14160	2,275	11,077	9,211	6,883	9,057	104.2
Arizona Common	F. C. 15837	2,312	10,847	10,607	5,198	8,884	102.3
New Mexico Common	F. C. 17430	2,919	10,183	9,756	6,646	8,862	102.0
Dakota Common	F. C. 16080	2,358	10,128	9,131	7,028	8,762	100.9
South African	F. C. 14203	2,226	10,232	9,810	6,166	8,736	100.6
Nebraska Common	F. C. 15897	2,143	10,495	8,883	6,697	8,692	100.0
Utah Common (check)	F. C. 15995	2,133	10,037	9,394	6,633	8,688	100.0
California (south)	F. C. 15889	2,446	10,645	10,677	4,544	8,622	99.2
Utah Common	F. C. 15937	1,873	9,919	8,925	6,917	8,587	98.8
Do	F. C. 15986	2,185	10,295	8,831	6,630	8,585	98.8
Hairy Peruvian	F. C. 15836	2,724	10,322	10,535	4,372	8,410	96.8
French	F. P. I. 81489	1,600	9,942	8,355	6,468	8,255	95.0
Grimm	F. C. 16030	2,352	9,187	8,285	7,199	8,224	94.7
French	F. P. I. 81488	2,133	9,414	8,473	6,464	8,117	93.4
California (north)	F. C. 15835	2,546	9,209	9,101	5,878	8,063	92.8
Turkistan	F. C. 15754	2,115	8,550	8,759	5,858	7,722	88.9
Do	Comm. 2674	2,085	8,960	8,037	5,112	7,370	84.8
India	Comm. 1724	2,831	5,937	[3]	[3]	[3]	[3]

[1] F. C. indicates accession number of the Division of Forage Crops and Diseases; F. P. I. of the Division of Foreign Plant Introduction; and Comm. indicates seed purchased from seedsmen.
[2] The 1930 yields are on a field-cured basis. Only 1 cutting was obtained, because of dry weather and spring sowing. Not included in averages.
[3] Winter-killed 1931–32.

The second test, sown October 7, 1932, included 12 of the more promising alfalfas. Each plot was repeated four times with every fourth plot a check of Kansas Common. In this test as shown in table 2, two strains of common alfalfa from Kansas gave slightly higher yields than any other variety. The 1-year results of the third test, sown September 14, 1933, are given in table 3 and are included primarily to show the comparatively low yields of the non-hardy alfalfas after a relatively cold winter.

TABLE 2.—*Annual and average yields of hay on a 12-percent moisture basis and percentage of check of variety test sown at Stoneville, Miss., Oct. 7, 1932*

Variety	Accession no.[1]	Acre yield			Percentage of check
		1933	1934	Average	
		Pounds	*Pounds*	*Pounds*	
Kansas Common (check)		6,774	11,525	9,150	100.0
Kansas Common	19972	6,510	11,628	9,069	99.1
Dakota Common	16083	6,452	11,554	9,003	98.4
New Mexico Common	19981	6,435	11,537	8,986	98.2
Argentine	15996	6,355	11,546	8,951	97.8
Utah Common	19961	6,323	11,421	8,872	97.0
Dakota 12	19958	6,310	11,335	8,823	96.4
Hardigan	19910	5,910	11,499	8,705	95.1
Ontario Variegated	19216	6,065	11,025	8,545	93.4
California Common	18899	5,691	11,381	8,536	93.3
Grimm	19967	6,047	10,975	8,511	93.0
Arizona Common	19911	3,574	10,598	7,086	77.4
Hairy Peruvian		1,966	8,174	5,070	55.4

[1] Of the Division of Forage Crops and Diseases.

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TABLE 3.—*1934 yields of hay by cuttings on a 12-percent moisture basis and percentage of check of the alfalfa variety test at Stoneville, Miss., sown Sept. 14, 1933*

Variety	Accession no.[1]	Acre yield						Percentage of check
		First cutting, May 2	Second cutting, June 14	Third cutting, July 16	Fourth cutting, Aug. 23	Fifth cutting, Oct. 15	Total	
		Pounds	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	
Ontario Variegated	19129	3,929	4,074	2,880	383	1,538	12,804	100.4
Kansas Com. (check)		3,989	3,725	2,924	444	1,677	12,759	100.0
Hardigan	20150	4,436	3,785	2,670	248	1,598	12,737	99.8
Disco 28		4,188	3,712	2,846	400	1,519	12,665	99.3
Grimm	22047	3,944	4,161	2,661	356	1,501	12,623	98.9
Oklahoma Common	18994	3,953	3,703	2,853	378	1,665	12,552	98.4
Dakota 12	19958	3,646	3,805	2,923	412	1,670	12,456	97.6
Nebraska Common	21598	3,887	3,712	2,851	319	1,622	12,391	97.1
Kansas Common	20091	3,629	3,718	2,871	332	1,763	12,313	96.5
New Mexico Com	19981	3,740	3,685	2,857	355	1,675	12,312	96.5
Argentine	15996	4,065	3,493	2,677	210	1,688	12,133	95.1
Arizona Common	21940	4,134	3,223	2,653	291	1,643	11,944	93.6
Utah Common	19961	3,743	3,523	2,737	291	1,625	11,919	93.4
Arizona Common	22027	3,675	3,376	2,582	238	1,846	11,717	91.8
California Common	22035	3,736	3,229	2,509	281	1,629	11,384	89.2
Turkistan	19316	3,643	3,329	2,474	324	1,414	11,184	87.7
Hairy Peruvian	21941	3,390	3,034	2,450	274	1,658	10,806	84.7
California Common	22041	3,472	3,083	2,331	177	1,528	10,591	83.0

[1] Of the Division of Forage Crops and Diseases.

These trials show clearly the risk involved in sowing nonhardy alfalfas in this portion of the Delta. Alfalfas from Kansas and adjoining States have given consistently good yields.

In addition to the tests at Stoneville, variety trials have also been carried on through cooperative agreement with the Northeast Louisiana Experiment Station at St. Joseph, La., approximately 120 miles south of Stoneville. The results of the first test sown October 27, 1930, are given in table 4. Over the 3-year period, 1931–33, Peruvian and Arizona Common alfalfa have given the highest yields. In a later test, sown November 6, 1931, the strains of southern common alfalfas gave the highest yields.

While these tests cover only a 3-year period, the results indicate that nonhardy alfalfas such as Hairy Peruvian and Arizona Common may be safely grown in this area.

TABLE 4.—*Annual and average yields of field-cured hay of the alfalfa-variety test sown at the Northeast Louisiana Experiment Station, St. Joseph, La., Oct. 27, 1930*

Variety	Accession no.[1]	Acre yield			Average
		1931	1932	1933 [2]	
		Pounds	*Pounds*	*Pounds*	*Pounds*
Hairy Peruvian	18841	14,103	10,793	1,546	12,448
Smooth Peruvian	18827	13,915	10,994	1,415	12,455
Arizona Common	18842	13,266	11,130	1,502	12,198
Utah Common	15986	12,073	11,371	1,760	11,722
Disco 28		12,515	10,801	1,590	11,658
Kansas Common	18826	12,937	10,191	1,481	11,564
Dakota 12	15997	13,047	10,345	1,132	11,696
Grimm	18840	12,503	10,411	1,132	11,457

[1] Of the Division of Forage Crops and Diseases.

[2] The third cutting, June 24, was the only cutting saved in 1933, due to continuous rains before and after that date; not included in averages.

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FERTILIZER EXPERIMENTS

At the beginning of the investigations very little information was available regarding the fertilizer requirements of alfalfa on Delta soils. From time to time planters have applied nitrogen and phosphatic fertilizers, with conflicting opinions regarding the effects. Because of this, investigations were inaugurated to determine definitely whether the soils are deficient in any of the elements essential to the successful growth of alfalfa. During the fall and winter of 1929–30, R. E. Uhland, who was in charge of the alfalfa investigations at that time, collected over 300 soil and subsoil samples from different locations in the Delta. These samples were analyzed for acidity, nitrogen, and soluble phosphorus, and the analyses showed that many of the Delta soils are low in nitrogen but well supplied with phosphorus.

In order to obtain further information on this subject a fertilizer test was sown in the fall of 1928 on a field of Sarpy silty clay loam of fair to good fertility, which included triplicate one-twentieth-acre plots of all treatments. The fertilizers were applied and disked in before seeding and reapplied immediately after the first cutting in 1931. As the small initial applications of nitrate of soda did not show any effect it was felt that this might be due to the insufficient amounts applied. Consequently, when the fertilizers were reapplied the amounts of nitrate of soda were doubled so that plots that had received 75 and 150 pounds were increased to 150 and 300 pounds, respectively.

The results, as shown in table 5, do not show any significant increases in yields of alfalfa hay from plots receiving applications of sulphur or nitrate of soda over the untreated checks. The plots receiving superphosphate and ground limestone, superphosphate alone, and ground limestone alone yielded during the 5-year period an average of 700, 685, and 497 pounds per acre, respectively, more than the check plots. While these yields are significantly higher than the yield from the untreated plots, the value of the increase in yield of hay from the use of fertilizers was not sufficient to compensate for the cost and application of the fertilizer.

Three other fertilizer tests are being conducted at Stoneville; 2 on Sharkey silty clay and 1 on Sarpy fine sandy loam. In these tests phosphatic, nitrogenous, and potassic fertilizers have been applied singly and in all combinations. Plots receiving manure and ground limestone have also been included. None of the tests has shown any significant increase in yield of alfalfa on plots treated with nitrogenous or potassic fertilizers. In fact, applications of nitrate of soda have, in several instances, depressed the yield. Applications of superphosphate, manure, and ground limestone have resulted in small increases in yield of alfalfa on Sharkey clay and have given significant increases on Sarpy fine sandy loam, but the increases have not been great enough to pay the cost of the fertilizer and the labor involved in applying it.

In addition to the fertilizer tests at Stoneville, field trials have been located at Clarksdale, Wilmot, and Arcola, Miss., and at St. Joseph, La. From observations of these plots no significant differences could be seen between the fertilized and the unfertilized plots.

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TABLE 5.—*Annual and average yields of hay on a 12-percent moisture basis, percentage of check, and increase over check from the alfalfa fertilizer test sown at Stoneville, Miss., Oct. 11, 1928*

Treatment (pounds per acre)	Acre yield						Percentage of check	Increase or decrease per acre on basis of check
	1929 [1]	1930 [1]	1931	1932	1933	Average		
	Pounds	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*		*Pounds*
Check (no fertilizer)	4,556	10,081	11,783	9,692	9,313	9,085	100.0	
300 superphosphate and 6,000 ground limestone	5,221	10,486	12,320	10,472	10,426	9,785	107.7	700
300 superphosphate	5,289	10,796	12,581	10,594	9,590	9,770	107.5	685
6,000 ground limestone	5,274	10,529	11,941	10,122	10,043	9,582	105.5	497
300 sulphur	4,609	9,148	12,508	10,092	9,847	9,241	101.7	156
150 nitrate of soda	3,767	9,815	11,994	9,970	9,668	9,043	99.5	−42
75 nitrate of soda	4,736	8,721	11,590	10,228	9,237	8,902	98.0	−183

[1] The average yields for 1929 and 1930 were on a field-cured basis. Low yields in 1929 were due to dry weather.

DATE AND METHOD OF SEEDING

The results of the date-of-seeding tests are shown in table 6. Sowing in the fall from September 15 to October 15 has consistently given good stands. As will be noted from the table, spring seedings in some instances have given fair stands, but the results on a whole indicate the risk involved in spring seeding. Late spring freezes have killed the young alfalfa on plots sown February 15 and March 1, while the invasion of grasses and weeds and periods of hot dry weather during late spring and early summer months usually have markedly reduced the stands on spring-sown plots. In addition to the difficulty in securing a stand of alfalfa in the spring, the yield of hay the first year is usually very low and of poor quality. However it is not uncommon to get relatively high yields of good-quality hay the first season from fall-sown alfalfa. It is a good practice to prepare the seed bed during August or early September and sow as soon as possible after the first good rain.

TABLE 6.—*Estimated annual average and average percentage of stand of alfalfa remaining at the end of the first growing season on plots sown at different dates at Stoneville, Miss.*

Date sown	1928–29	1930–31	1931–32	1932–33	1933–34	Average
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Sept. 15	100.0	93.0	82.0	100.0	91.0	93.2
Oct. 1	100.0	94.0	83.0	100.0	91.7	93.7
Oct. 15	83.0	77.0	80.0	100.0	86.7	85.3
Nov. 1	45.0	58.0	28.0	0	79.3	42.1
Nov. 15	0	0	33.0	0	0	6.6
Feb. 15	0	75.0	13.0	(1)	71.3	39.8
Mar. 1	0	46.0	65.0	35.0	70.0	43.2
Mar. 15	8.0	45.0	70.0	7.0	55.3	37.1
Apr. 1	73.0	83.0	13.0	4.0	39.0	42.4
Apr. 15	(1)	83.0	13.0	2.0	4.0	25.5

[1] Plots not sown these years.

The alfalfa drill distributes the seeds evenly and covers them uniformly, and where large fields are to be sown the purchase of this implement would be a sound investment. In using this implement

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on loam soils care should be taken to avoid covering too deeply. Excellent stands of alfalfa may also be obtained with the wheelbarrow seeder, if properly operated. In seeding with a wheelbarrow seeder it is advisable to sow half of the seed in one direction and the other half across the first seeding. The seed should be covered lightly with a spike-tooth harrow.

The use of the long box drag in the final preparation of the seed bed for alfalfa has been found to be indispensable on Delta soils. The drag not only smooths the field by filling in small depressions but aids materially in pulverizing the soil. If a corrugated roller or cultipacker is available the field should be rolled before seeding to improve the tilth and compact the seed bed.

RATE OF SEEDING

The rate of seeding varies considerably in the Delta area. A few fields are sown at rates as low as 12 pounds per acre, many more from 15 to 25 pounds, while the majority of the fields are sown at rates ranging from 25 to 40 pounds per acre. The results of the rate-of-seeding test are shown in table 7. There are no significant differences between the yields of plots sown at the different rates of seeding. Plots sown at the rate of 10 pounds per acre gave yields as high as those sown at the higher rates. The 2-year results of a later test, sown October 8, 1932, are in accord with the test reported in table 7. Although seeding at the rate of 10 pounds per acre gave as high yields as the heavier rates in these tests, it is probable that more care was taken in preparing the seed bed and in seeding than under general farming practices. For these reasons seeding at the rate of 15 to 20 pounds per acre is advisable, depending on the condition of the seed bed and method and time of seeding. Spring seedings should be heavier than fall seedings owing to greater weed competition and to more adverse weather conditions.

TABLE 7.—*Annual and average yields of hay on a 12-percent moisture basis from the rates-of-seeding-alfalfa test sown in duplicate plots, Oct. 11, 1928, at Stoneville, Miss.*

Rate of seeding (pounds per acre)	Acre yield						Average
	1929 [1]	1930 [1]	1931	1932	1933	1934	
	Pounds	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*
10	8,020	9,450	9,968	10,284	7,317	10,750	9,298
20	8,240	9,260	10,398	9,722	7,373	10,895	9,315
30	8,300	9,370	9,559	10,326	8,044	11,744	9,557
40	8,000	9,090	9,827	10,730	8,141	11,189	9,496
50	8,300	9,670	9,616	9,793	7,573	11,262	9,369

[1] Yields on a field-cured basis.

CULTIVATION

Cultivating old or thin stands of unirrigated alfalfa immediately after each cutting or at any other time usually has proved unprofitable, and in this respect the results of two 3-year cultivation tests are in accord with the findings of other investigators. The disk harrow, rotary hoe, and the spring-tooth harrow or alfalfa cultivator

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are being used, and the results of the first test sown in the fall of 1928 are shown in table 8. Yields from plots cultivated immediately after each cutting or in the spring and late summer have been consistently lower than the yields from uncultivated plots. There have been no apparent differences in the percentage of grass in the hay from the cultivated and uncultivated plots. The reduction in stand on many of the plots is very apparent, particularly on those plots which have been disked after each cutting.

TABLE 8.—*Annual and average yields of hay on a 12-percent moisture basis, and decrease due to cultivation from the alfalfa-cultivation test at Stoneville, Miss.*

Implement used	Time of cultivation	Acre yield				Percentage of check	Decrease (per acre) due to cultivation
		1932	1933	1934	Average		
		Pounds	*Pounds*	*Pounds*	*Pounds*		*Pounds*
Check, not cultivated		9,268	6,655	9,728	8,550	100.0	
Rotary hoe	After each cutting	9,352	6,490	9,324	8,389	98.1	161
Do	Spring and late summer	9,490	6,097	9,438	8,342	97.6	208
Disk harrow	do	9,472	6,304	9,197	8,324	97.4	226
Spring-tooth harrow	do	9,195	6,400	9,263	8,286	96.9	264
Disk harrow	After each cutting	9,312	6,501	8,640	8,151	95.3	399
Spring-tooth harrow	do	8,870	6,697	8,875	8,147	95.3	403

TIME OF CUTTING

While cutting tests have not been conducted long enough to permit definite recommendations for conditions in the Mississippi Delta, the results do indicate the importance of cutting alfalfa at the proper time. In general, the results are in agreement with the conclusions reached by investigators in other alfalfa-producing sections, in that alfalfa cut at the one-tenth to one-half bloom stage produces maximum yields of good-quality hay without appreciably injuring the stands. While cutting at the prebud and bud stage produces high-quality hay, if all cuttings are made early the stands begin to thin out to such an extent that by the end of the second season the field is mostly grass and weeds. Also the annual yields of alfalfa cut at the early bud stage have been lower than when cut at later stages. Slightly lower yields of poor-quality hay have resulted from cutting later than the three-fourths to full-bloom stage. Livestock men have long recognized that hay made from alfalfa cut in the late-bloom stage is a better feed for mules and horses than hay from cuttings made at the earlier stages, and since most of the alfalfa produced in the Mississippi Delta is fed to work stock it should be cut when one-half to three-fourths in bloom.

At certain periods during the growing season, due to adverse climatic conditions, alfalfa does not bloom readily, and under these conditions the stage of bloom is not a satisfactory guide to the time to cut. When this occurs alfalfa should be cut when it begins to take on a yellowish cast, as this condition indicates that the vegetative growth is slowing up or has stopped entirely. Under these conditions, by frequent observations of their fields, alfalfa growers soon learn when to cut.

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DRAINAGE

As the annual average rainfall in the Mississippi Delta varies between 50 and 60 inches, the problem of securing adequate drainage is of major importance. Poor drainage on the broad nearly level basins of Sharkey clay is the cause of more alfalfa failures than any other factor. Experiments have been conducted to determine the effect of tile and surface drainage on yields and survival of alfalfa.

TILE DRAINAGE

As most of the large areas of Sharkey clay have been drained by primary and secondary dredge ditches, it was thought that tile drains would adequately drain the areas between the ditches. To test this, an area of Sharkey clay was chosen, one-half of which was tiled and the other half left to serve as a check. Equally good surface drainage was provided for both areas. The tile drains were installed in August 1930 and consisted of 4 lines of 6-inch clay tile, each line being 225 feet long and spaced at 30-foot intervals. A good seed bed was prepared on both sections, and the alfalfa was sown October 13, 1930. Yields of hay have been taken on the two areas over the 4-year period 1931–34 and show no significant differences between the yields of the tile-drained area and the untiled area. This failure to obtain any appreciable benefits with tile drainage on Sharkey clay is in accord with observations of planters who have tried tile drainage in this locality.

SURFACE DRAINAGE

From observations of fields of alfalfa on Sharkey clay it has been noted that wherever good natural surface drainage occurs, good stands of alfalfa are maintained, but where it has been sown on the flat, poorly drained areas the stands are thin, grassy, and unproductive after 2 or 3 years. It is evident that the natural slope of these nearly level lands is not great enough to remove surface water in time to prevent injury to the stands during the winter months when the rainfall is usually excessive. Most of the alfalfa grown at the experiment station at Stoneville is on fields which have been built up into lands providing very good surface drainage. On some of these fields it has remained productive for 5 to 7 years. As such good results were obtained on these fields, it became evident that information as to the height to which fields should be built up was very much needed.

A surface-drainage test was installed on D. T. Wilkins' plantation near Wilmot, Miss., to determine the height to which lands should be built and also the width of land most suitable for general use. Lands were built up from 6 to 14 inches, varying in width from 50 to 130 feet. The ditches between these lands were of the V-type with flat slopes, and may be readily crossed with haying equipment. The fall in the ditches approximated 2 inches per 100 feet. Two lands were left flat to serve as checks. The field was sown to alfalfa in October 1930, good stands being obtained over the entire field. The stands on lands left flat were very poor following the winter of 1930–31, and attempts to reseed these areas in the fall of 1931 met with little success. When last observed in the fall of 1934 the

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alfalfa on the flat lands had died out from 80 to 100 percent, while the stands were still good on the other lands. There were no noticeable differences on the lands built up to different heights or of varying widths, the stand being equally as good on those lands built up 6 inches as on the higher ones.

In preparing a field of level or nearly level Sharkey clay for alfalfa, the entire field should be built up into lands to provide adequate surface drainage. The lands should always run with the slope of the field. The width of the lands will depend largely on the equipment the planter has on hand, such as graders, scrapers, etc. On fields having a uniform slope, lands 30 or 40 feet wide may be built up sufficiently by plowing each land to the center and opening up the ditches with a ditcher or grader, care being taken to see that the soil is moved well back from the ditch banks so that the surface water may enter the ditches readily. Further investigations are being conducted with different implements on lands of varying widths, the results of which will be reported later.

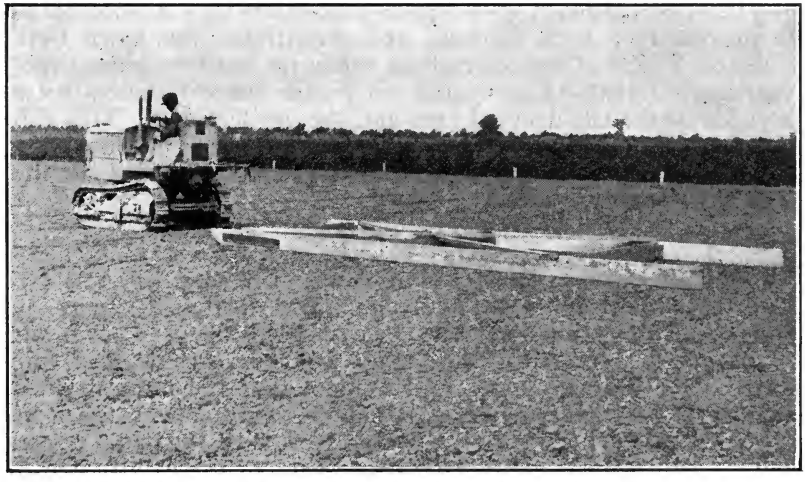

FIGURE 1.—Box drag used in smoothing land for alfalfa.

In the final preparation of the seed bed, the long box drag has been found to be very useful in smoothing the land by dragging off the high spots and filling in the low ones. A box drag that has done satisfactory work on the experiment station is shown in figure 1, the working plan being shown in figure 2.

The following materials will construct such a drag:

2 runners, 2 by 8 inches by 20 feet.
3 cross members, 2 by 8 inches by 7 feet.
2 diagonal braces, 2 by 4 inches by 15 feet 8 inches.
6 angle irons, ¼ by 3 by 3 by 8 inches.
2 iron straps, ⅜ by 6 by 24 inches.
26 bolts, ½ by 2½ inches.
2 eye bolts, ⅝ by 3 inches.

This drag is of inexpensive construction, light in weight, and can be easily moved from one field to another. The runners are extended in the rear to prevent the rear end from scooping out holes

when the front end is elevated. The drag should be at least 20 feet long so that its action on the land will be one of levelling and not of rising and falling with small surface irregularities. Such a drag will do excellent work without any additional weight on light soils, but on the heavy "buckshot" soils it may be necessary to place a sack of soil on each of the four corners of the drag to weight it down. As the drag leaves the soil loose in places it is a good practice to roll the land with a corrugated roller or cultipacker before sowing. Fields plowed or built up into lands should be allowed to settle from 2 to 3 weeks before seeding, as alfalfa requires a firm seed bed.

INSECTS AND DISEASES

While yields undoubtedly have been lowered in many instances by alfalfa diseases, the stands have not been seriously reduced by any one disease since the investigations were started. In some of the older fields in this section plants infested with bacterial wilt

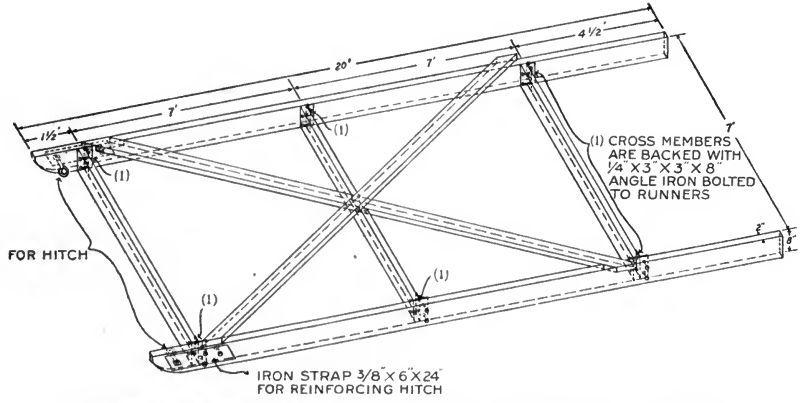

FIGURE 2.—Working plan for constructing box drag, shown in figure 1.

(*Phytomonas insidiosa* (McCulloch, Bergey et al.) are sometimes found, but no serious spread or material reduction in stands has been noted as a result of this disease. Leaf spot caused by the fungus *Pseudopeziza medicaginis* (Lib.) Sacc. is probably the most serious disease of alfalfa in the Delta area. The disease appears as small dark-brown to black spots on the leaves, which cause the badly infected leaves to turn yellow and to drop off. Leaf spot is especially noticeable when the normal rate of growth of alfalfa is retarded by environmental conditions.

Alfalfa fields in the Mississippi Delta are generally infested with numerous insects; the degree of injury from these insects depending largely on seasonal conditions. The pea aphid (*Illinoia pisi* Kalt.) is usually present in large numbers during cool spring months and may cause considerable damage to the first crop if the time of cutting is delayed. The three-cornered alfalfa hopper (*Stictocephala festina* (Say)) is usually present at the time of the third and fourth cuttings and by girdling the stems will cause a yellowing of the foliage. The damage to the hay may be checked and the insect

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partially controlled by cutting the alfalfa at the time the first yellowing appears. At midseason, leafhoppers (*Empoasca* spp.) may be present in such large numbers as to cause a yellowing of the foliage, as a result of the insects feeding on the stems and petioles of the plant. The fall army worm (*Laphygma frugiperda* S. and A.) may appear in large numbers and if not controlled will sometimes ruin newly sown fields and in established stands the last cutting may be defoliated by this worm. Many of the Delta planters have been able to control the fall army worm in newly sown stands by dusting with calcium arsenate at the rate of 4 to 6 pounds per acre. Further information on alfalfa insects and their control can be obtained by addressing inquiries to the Bureau of Entomology and Plant Quarantine, Washington, D. C.

SUMMARY OF RESULTS

In an effort to determine the cause of alfalfa failures in the Mississippi Delta, investigations covering the most important phases of alfalfa production are being conducted at Stoneville. The principal tests included in the investigations are variety and fertilizer trials, rates and dates of seeding, cultivation, time of cutting, and tile- and surface-drainage tests. In addition to the experimental tests, frequent observations are made of fields of alfalfa within short distances of Stoneville, and notes are taken regarding the condition of stands, presence or absence of diseases, etc.

Some of the unsatisfactory results have been due to attempts to grow alfalfa on unadapted soils. The older soils of the Yazoo series and the better drained phase of Sharkey clay in the eastern part of the Mississippi Delta are acid, and alfalfa usually fails on them. In some instances, poor seed-bed preparation has been responsible for the failure to secure good stands of alfalfa.

The results indicate that while the nonhardy strains of alfalfa may be satisfactorily grown as far north as St. Joseph, La., they are not adapted to the northern portions of the Mississippi Delta. Strains of common alfalfa from Kansas and adjoining States have given very satisfactory yields and should be grown in preference to northern cold-resistant alfalfa or Hairy Peruvian and other nonhardy varieties.

Attempts to increase the yield or life of stands by applications of commercial fertilizers have shown little promise.

While plots sown at the rate of 10 pounds of seed per acre have yielded as well as those sown at the higher rates, in general farm practice it is advisable to increase this rate to 15 to 20 pounds per acre.

By far the best results have been obtained from seedings made in the fall from September 15 to October 15.

The quality or yield of alfalfa hay has not been increased by any form of cultivation.

Results of time-of-cutting tests indicate that satisfactory yields are obtained without appreciably injuring the stands when alfalfa is cut at the one-tenth to one-half bloom stage.

From observations of many fields in the Mississippi Delta, and from experimental results, it is evident that the lack of surface

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drainage is responsible for most of the unsuccessful attempts to grow alfalfa. The nearly level to level areas of Sharkey clay "heavy buckshot" soils make ideal alfalfa soils if properly surface-drained. However, the tests have shown that the natural drainage on these areas should be supplemented by building up the field into lands with surface ditches, spaced at regular intervals to drain the field more rapidly.

The various insects and diseases found have not been a major factor in the alfalfa failures.

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DECAY FOLLOWING FIRE IN YOUNG MISSISSIPPI DELTA HARDWOODS

By

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UNITED STATES DEPARTMENT OF AGRICULTURE, WASHINGTON, D. C.

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UNITED STATES DEPARTMENT OF AGRICULTURE

WASHINGTON, D. C.

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Assistant pathologist, Division of Forest Pathology, Bureau of Plant Industry

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INTRODUCTION

The Delta area of the lower Mississippi River extends from the vicinity of Cape Girardeau, Mo., to the Gulf of Mexico, comprising the present and former flood plains of the river and portions of the bottom lands of a number of the important tributaries. It occupies a north and south belt approximately 600 miles long, and from 30 to 115 miles wide. Its total area is variously estimated as between 24,000,000 and 29,000,000 acres, according to the quantity

[1] The subject matter of this bulletin was submitted to the Graduate School of Cornell University in partial fulfillment of the requirements for the degree of doctor of philosophy.

[2] The writer wishes to express his thanks to Carl Hartley, of the Division of Forest Pathology, U. S. Department of Agriculture, under whose direction this study was carried on, for his interest, suggestions, and cooperation; to F. H. Kaufert, formerly of the same Division, for his suggestions and assistance; to F. X. Schumacher, of the Forest Service, U. S. Department of Agriculture, for his direction in the statistical analysis of the data; and to the Thistlethwaite Lumber Co., the Poinsette Lumber Co., and the other agencies that permitted trees to be cut on their lands; to R. W. Davidson, of the Division of Forest Pathology, U. S. Department of Agriculture, and F. H. Kaufert, who assisted materially in the determination of the fungi; and to R. A. St. George, T. E. Snyder, and A. G. Boving, of the Bureau of Entomology and Plant Quarantine, U. S. Department of Agriculture, and to William Mann, of the U. S. Zoological Park, Washington, D. C., for the identification of most of the insects.

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of bottom lands of the tributaries that are included.[3] This is one of the important hardwood-producing areas in the United States (*11*).[4] There are, roughly, 40 species of commercial importance within the area, oak, red gum, cypress, ash, and cottonwood being of greatest value. In spite of the importance of this region, there had been practically no professional forestry investigations in the Delta prior to 1928 and no forest pathological work until 1931 when Kaufert (*7*), working with L. O. Overholts, made a preliminary pathological reconnaissance.

Until recent years fire was considered of little importance in the Delta, partly because the area was thought to be too moist for frequent fires, and partly because it was thought by timberland owners that fire did little damage to hardwood timber. Both of these reasons have subsequently been shown to be false. As will be shown later, practically every year some part of the Delta burns; and in dry years in the past, large portions of this area have burned over. The dry spring and fall months of the 1910–11, 1916–17, 1917–18, and the 1924–25 seasons are examples. Because it is not possible to tell by ring counts whether a tree was burned in the fall of a given year or in the spring of the following year, preceding the growth period, the terms "fire season" and "fire year" will include both of these periods. That is, the fire year 1924–25 includes the fall of 1924 and the spring of 1925. Lentz (*11*) estimates that 80 to 90 percent or more of the hardwood stands in the bottom lands were found to have burned over in 1916, in the 1924–25 fire season, or during both of these periods.

The predominant fuel is leaf litter. While this litter of leaves and small twigs rarely exists for more than a year, because of its rapid decomposition, 1 year's accumulation, together with the undergrowth, is sufficient to produce a hot fire, in dry weather, which severely wounds the bases of the trees.

The chief causes of fire in the bottom lands are hunters and trappers who start fires to drive out game or to make the cut-over lands more accessible; loggers; farmers who, clearing land for cotton, permit their fires to run into the woods; and local woodchoppers who leave their warming fires without extinguishing them.

Surface fires, no matter how light, have a devastating effect on young growth. Seedlings and small reproduction are killed outright; saplings and poles, because their relatively thin bark offers little resistance to fire, are wounded at the base and sometimes completely girdled; and merchantable trees are wounded or killed. The wounding of trees by fire is well discussed by Lachmund (*8*, *9*) and by Nelson, Sims, and Abell (*16*).

The effect of fire scars on hardwoods is threefold. There is a mechanical weakening because of the cessation of increment over the scarred area; there is an interruption in the normal physiological functions of translocation of food, nutrients, and water; and, most important of all, the tree is exposed to the entrance of wood-destroying fungi and insects. These fungi may either so weaken the tree at the

[3] WINTERS, R. K., and BULL, H. THE GEOLOGICAL AND ECONOMIC BACKGROUNDS OF FOREST CONDITIONS IN THE LOWER MISSISSIPPI DELTA. U. S. Dept. Agr., Forest Serv. South. Forest Expt. Sta. Mimeographed Pub. pp. 1–7. 1932.

[4] Italic numbers in parentheses refer to Literature Cited, p. 31.

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base that it breaks over, or else, if the tree remains in the stand, the fungi work upward in the bole, causing a reduction or complete loss of the merchantable portion of the tree.

Hedgcock (*5*) states that investigations in hardwood forests indicate that more than 90 percent of all basal or butt rots enter through fire scars. In the Delta area this figure might be raised still higher and be allowed to include trunk rots as well as butt rots. As yet there is little evidence of serious trunk rots in this area, excepting those that gain entrance through fire scars. *Polyporus hispidus* Fr., however, is a fungus which causes a trunk rot in bottom-land hardwoods and which can gain entrance through wounds other than fire scars.

Since the principal problem in the Delta hardwoods at the present time is the future of the cut-over lands and the immature stands, the present study is concerned with the effects of fire in immature stands, throughout the Delta, by permitting infection by wood-destroying fungi and invasion by insects. The purposes of this study were to secure information on the following points: (1) The importance of fire in causing the breaking over of young trees from decay at the base, (2) the importance of fire in causing cull in the surviving trees at a future date, (3) the relative susceptibility of certain important species to decay, (4) the organisms responsible for the decays, (5) the rate of healing of fire scars, and (6) insect activity behind fire scars. The study was instigated chiefly to provide the Forest Survey, United States Forest Service (*13*), now working in the Delta hardwood area, with information on the role of fungi in causing depletion in fire-scarred immature stands. The field work was done during the late spring, summer, and fall of 1932.

DESCRIPTION OF WORKING AREAS

On the basis of relative elevation, the Mississippi Delta can be divided into two broad classes, the first bottoms and the terraces. The first bottoms embrace the present flood plain of the river, and the terraces comprise what remains of the former and higher flood plains. All of the working areas in the present study were within the first bottoms. These bottoms are practically flat, with occasional ridges ranging from 2 or 3 feet to about 15 feet in elevation above the flats. The soil is predominantly heavy clay ranging to silty clay and silt loam, with little or no humus covering. There is considerable fine sand along stream fronts and ridges. The flats, while normally dry from late spring until fall, are more or less under water for the remainder of the year. Slight changes in elevation, with accompanying changes in soil (for example, from clay in a flat to a silty loam in a ridge) produce marked changes in forest types. Red gum, often in almost pure stands, is an indicator of ridge soil. Overcup oak and water hickory indicate a poorly drained flat. Water oak, willow oak, and Nuttall oak commonly accompany red gum on the better sites, while ash is usually found on the heavier soils. There is naturally much overlapping of types.

In choosing the species of trees to be studied, those which were considered to have the greatest economic value were selected. The following species were studied, in order of preference: Red gum

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(*Liquidambar styraciflua* L.), ash (*Fraxinus americana* L. and *F. pennsylvanica lanceolata* (Bork.) Sarg.), Nuttall oak (*Quercus nuttallii* Palm.), water oak (*Q. nigra* L.), overcup oak (*Q. lyrata* Walt.), cherrybark oak (*Q. rubra leucophylla* Ashe, and *Q. rubra pagodaefolia* (Elliot) Ashe), willow oak (*Q. phellos* L.), hackberry (*Celtis laevigata* Willd.), and persimmon (*Diospyros virginiana* L.). These names are as given by Putnam and Bull.[5] Cottonwood and willow, also of importance, are confined mainly to the batture lands lying between the levees and the river, and would more logically constitute a separate study. They were omitted in this investigation.

As the purpose of this study was to supply information relating to the Delta as a whole, working areas were chosen at widely scattered points over the Delta. Trees were sampled from 7 sections in East Carroll and Madison Parishes in northeastern Louisiana, from 4 in St. Landry and Pointe Coupee Parishes in southern Louisiana, from 5 in Sharkey and Issaquena Counties in western Mississippi, and from 4 sections in Panola County in northwestern Mississippi. Working areas that met the following qualifications were chosen: A large proportion of fire-scarred trees; a stand consisting mainly of the species with which the study was concerned, the trees being within the required diameter limits of 3 to 11 inches, breast high; and accessibility. Because much of the Delta has burned over at least once in the past 20 years, there was no problem in finding burned areas. However, as a large proportion of the scars were found to have been formed during the bad fire season of 1924–25, and many of the remainder were formed in the fire season of 1917–18, it was not possible to secure a good distribution of scar ages for the study.

Nine of the working areas were located in the forest type recognized as "red gum" by the Forest Survey[6], 9 were in the mixed hardwood type, and 2 were in the overcup oak-pecan type. All of the stands were second-growth, and some had been old fields.

A total of 602 fire-scarred trees were cut and dissected, consisting of 213 red gum, 101 ash, 76 Nuttall oak, 69 water oak, 35 overcup oak, 14 willow oak, 10 cherrybark oak, 66 hackberry, and 18 persimmon.

FIELD METHODS

Only trees with visible fire scars, open or healed, were chosen for analysis. Since completely healed fire scars on young trees are rare, the exclusion of those healed beyond identification will have little effect on the results obtained. The principal reason why so few completely healed scars are found is because, on the average, these young trees have such large scars. In the species studied, fire scars occupied, on the average, 49 percent of the circumferences of the trees, measured where the scar was widest.

Plots were not laid out because in many cases there were but few desirable trees over a large area, as, for example, on recently cut-

[5] PUTNAM, J. A., and BULL, H. THE TREES OF THE MISSISSIPPI RIVER DELTA REGION. U. S. Dept. Agr., Forest Serv. South. Forest Expt. Sta. Mimeographed Pub., 207 pp. 1932.

[6] LENTZ, G. H. FIELD MANUAL FOR THE FOREST SURVEY IN THE BOTTOMLAND HARDWOODS OF THE MISSISSIPPI DELTA. U. S. Dept. Agr., Forest Serv. South. Forest Expt. Sta. Mimeographed Pub., pp. 12–14. 1932.

over land. Instead of laying out plots, the crew, composed of two men, walked back and forth over the area, cutting all fire-scarred trees of the desired species and size as they came to them. Trees were omitted only if they had wounds other than fire scars, which would make it impossible to determine definitely the entrance point of decay, or if the trees were so badly scarred that it was impossible to tell the age and extent of the scars. Rarely did a tree have to be discarded for either of these reasons. The trees were cut at the height at which the scar occupied the largest proportion of the circumference of the tree.

An impression was taken from the top of the stump of each tree, showing the former and present outlines of the scar, and the outlines of the decay. This impression was made by marking all desired outlines on the stump with a soft indelible pencil. Sheets of paper were then moistened and placed on the stump. By pressing the paper over the outlines a satisfactory print was secured. In this way it was possible to secure impressions of the decayed portion of the cross-sections, which were later planimetered to determine the area of decay. Measurements of the original and present width of scars were also made from these impressions.

All measurements, excepting diameter, were taken in feet and tenths of feet. Decay was measured as linear extent rather than as volume, as there is logically no cull in trees below merchantable size. After felling, the trees were sawed into sections and split, if decayed, to show the extent of decay. The ages of the fire scars were determined by ring counts on the callus folds. In most cases these ages could be ascertained accurately, but in red gum, particularly, the production of false rings often made exact counts impossible. In such cases the fire history of the neighboring trees was an aid. Tree ages were determined on the stump wherever possible, and where not possible were adjusted to age-on-stump on a basis of 2 feet of height growth per year. This rate was chosen arbitrarily, as no studies on rate of seedling growth have yet been made in the Mississippi bottom lands.

Whenever possible, cultures were made from the decayed trees, to determine the fungus causing the decay. In many cases there were merely hollows with firm walls, and no decay beyond. Several attempts were made to culture from the wood just above the hollow, in such trees, but no pure cultures of wood-destroying fungi were secured from them. In every case of typical decay, one culture was made from the typical rot and one from the incipient rot at the top of the decay column. Blocks of the decayed wood from which cultures were to be made were cut out of the trees in the field and placed in paper bags. The same night the blocks were split open and small pieces cut out with a sterile scalpel and placed in test tubes on 1½ percent malt agar at a pH of about 5. This was a very favorable medium for these fungi. At the high temperatures prevailing in the summer months, the fungi grew out from the slivers onto the agar within 1 to 3 days. A large amount of culturing was essential for the identification of the causal fungi of the decays because fruiting bodies on the fire scars are very rare in this area, and because sufficient facts are not yet known concerning these Delta

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hardwood decays to distinguish one rot from another, macroscopically, with any degree of assurance.

In addition to culturing from the dissected trees, cultures were made from a large number of sporophores collected in the field. The object of this was to build up a collection of known cultures with which the unknown decay cultures could later be compared for identification. These sporophore cultures supplemented similar cultures made by Overholts and Kaufert from the same area.

Wherever insects were found in association with fire scars, specimens were collected. These were forwarded to the Bureau of Entomology and Plant Quarantine for identification.

FREQUENCY OF FIRES

In the introduction, it was stated that fires were of frequent occurrence in the Delta, and that they were particularly prevalent in certain dry years. Table 1 is based on the results of an analysis of the fire scars on the 602 trees cut from the 20 areas sampled, and shows the number of trees scarred each year. This analysis shows that, with few exceptions, in each of the past 30 years, at least one of these areas has burned over.

TABLE 1.—*Fire years as determined by scarred trees*

Year	Trees scarred	Year	Trees scarred	Year	Trees scarred	Year	Trees scarred
	Number		*Number*		*Number*		*Number*
1930–31	49	1921–22	9	1912–13	2	1902–03	3
1929–30	8	1920–21	8	1911–12	6	1901–02	1
1928–29	50	1919–20	8	1910–11	19	1899–1900	10
1927–28	10	1918–19	1	1909–10	4	1897–98	1
1926–27	35	1917–18	135	1908–09	1	1894–95	4
1925–26	2	1916–17	4	1906–07	1	1890–91	1
1924–25	309	1915–16	11	1905–06	3	1867–68	1
1922–23	5	1914–15	15	1903–04	1		

Certain years stand out as exceptionally bad fire years. Over the areas studied, the fire year 1924–25 stands out as the worst. This is consistent with the findings of Lentz (*11*, *12*) and Kaufert (*7*). Prior to 1924 the worst fire years appear to be 1917–18, 1914–15, 1910–11, and 1899–1900. While the last four seasons are somewhat at variance with the seasons given by Kaufert as being particularly bad prior to 1924, this discrepancy may be due to the samples having been taken from different localities. Table 1 shows that fires occurred at least as far back as 1867, and that they are still of frequent occurrence in the Delta.

FORMATION OF FIRE SCARS

As there is almost always some accumulation of twigs and larger material at the bases of the trees, intense heat is generated there during slow-burning surface fires, with the result that large areas, if not all, of the living bark and cambium tissues near the base are killed. The bark adheres for a year or two and then drops off, exposing the sapwood of the scarred areas. A single fire rarely ever burns through the bark into the wood, although subsequent fires may hollow out a previously scarred tree. Plate 1 shows two groups of trees that are typical of fire-scarred young Delta hardwoods.

A, A group of young hackberry trees with 7-year-old fire scars, showing a tree broken over because of decay following scarring. (Photographed by F. H. Kaufert.) *B*, A group of young Nuttall oaks with 8-year-old fire scars, showing a tree broken over at the scar.

A, Overcup oak scarred 21 years and again 15 years before photographing. This tree never would have had merchantable value. *B*, A 68-year-old overcup oak with a 15-year-old fire scar. The typical decay extends above the level of the end of the ax handle. The decay was caused by an unidentified yellow hymenomycete. *C*, Young Nuttall oak with 7-year-old fire scar, showing heart rot running up from the scar.

In the field there was an apparent difference in the susceptibility of different species to scarring. In several stands composed mainly of hackberry and red gum, a large proportion of the thin-barked hackberry trees were found to be scarred, while but few of the relatively thick-barked red gum showed scars. However, as shown in table 2, if any of the species studied were scarred at all, the scars, on the average, were much the same size on all. All species taken together, the average fire scar occupied 49 percent of the tree circumference at the point where the scar was widest. None of the species studied varied essentially from this average. The length of scars ranged from about 6 inches to 10 feet, with an average of a little over 2 feet. Small scars on these young trees were uncommon, but it is to be noted that such very small scars as were formed may have completely healed and so remained unnoticed.

TABLE 2.—*Average percentage of tree circumference scarred,*[1] *by species*

Species	Number of scars measured	Average percentage of circumference occupied by scar[2]	Species	Number of scars measured	Average percentage of circumference occupied by scar[2]
Red gum	215	50	Willow oak	13	44
Ash	101	48	Cherrybark oak	10	52
Hackberry	68	48	Persimmon	20	42
Nuttall oak	78	49			
Water oak	71	50	All trees	610	49
Overcup oak	34	50			

[1] Those scars, the original limits of which were obliterated through decay, were omitted from this table.
[2] Measurements made at widest part of scar.

RATE OF HEALING OF FIRE SCARS

Completely healed scars, unless they had been very small to begin with, were rare. This is not because these Delta hardwoods do not heal wounds rapidly, but because the exposed scarred areas usually soon become hollowed out by fungi and insects (pl. 2), leaving no surface for the callus folds to heal over. It is for this reason that many trees that were scarred 30 and more years ago still have open scars.

In order to determine the relative rate of scar-healing of the various species studied, healing was measured only on those trees with a complete, firm, original surface for the callus folds to heal over, as shown in figure 1. Some of the trees chosen were decayed, but the decayed wood was firm enough to support the callus. Table 3 compares the various species as to their rates of healing. For example, a red gum tree with a scar 2.8 inches wide, healing at a rate of 0.56 inch per year, would be expected to be completely healed in 5 years, provided the exposed wood was not hollowed out by that time. Table 3 shows that the oaks and red gum heal most rapidly, followed by ash, hackberry, and persimmon. While the differences in rates between certain species are not significant, the table shows the relative rates for the different genera. Figure 1 shows a section from the base of a red gum tree which was scarred badly in 1910 and very badly in 1917. This tree had remained sound. Its first scar

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was completely healed, and its second, which had almost girdled the tree, was nearly healed.

TABLE 3.—*Rate of healing, by species*[1]

Species	Cases	Cases—			Average amount of scar covered per year	Standard error
		Over-topped	Inter-mediate	Codominant and dominant		
	Number	*Percent*	*Percent*	*Percent*	*Inches*	
Overcup oak	7	71	14	15	0.76	[2]
Nuttall oak	28	32	25	43	.67	±0.07
Red gum	111	23	48	29	.56	±.02
Willow oak	8	50	0	50	.55	[2]
Water oak	30	17	53	30	.54	±.04
Ash	34	26	41	33	.43	±.03
Hackberry	13	31	54	15	.39	±.05
Persimmon	9	44	33	23	.31	[2]

[1] Only trees with firm surface to heal over are included. Healing measured on cross section of scar as linear inches of callus formed over wound. Figures represent totals of both callus folds.
[2] Standard error of no value with so few cases.

INFECTION OF SCARRED TREES BY FUNGI

The terms "decayed" and "sound" as applied to the condition of trees are used frequently throughout this bulletin and are defined, for the purpose of this study, as follows: A decayed tree is a tree in which the surface of the scar is decayed to a depth of one-half inch or more; a sound tree is a tree in which decay has progressed to a depth of less than one-half inch beneath the scar surface. Border-line cases were uncommon, however, so that trees designated as decay cases were usually definitely rotted, as shown in plates 2, 3, and 4.

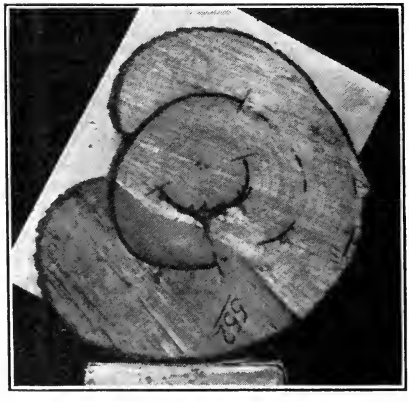
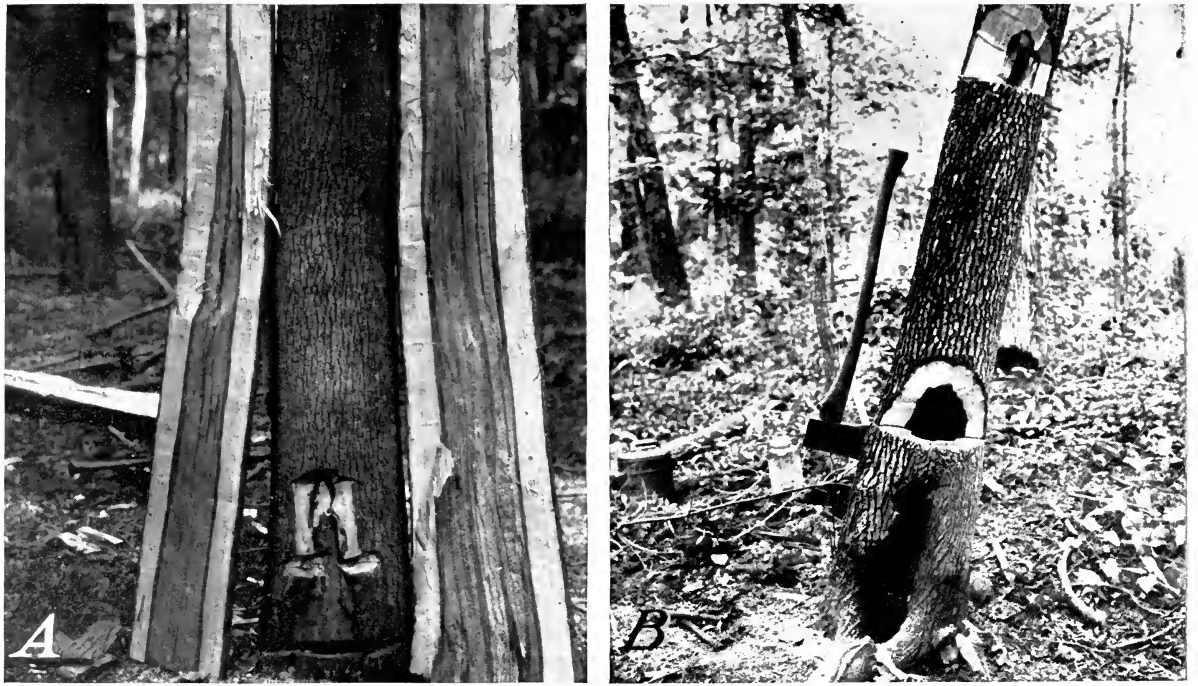
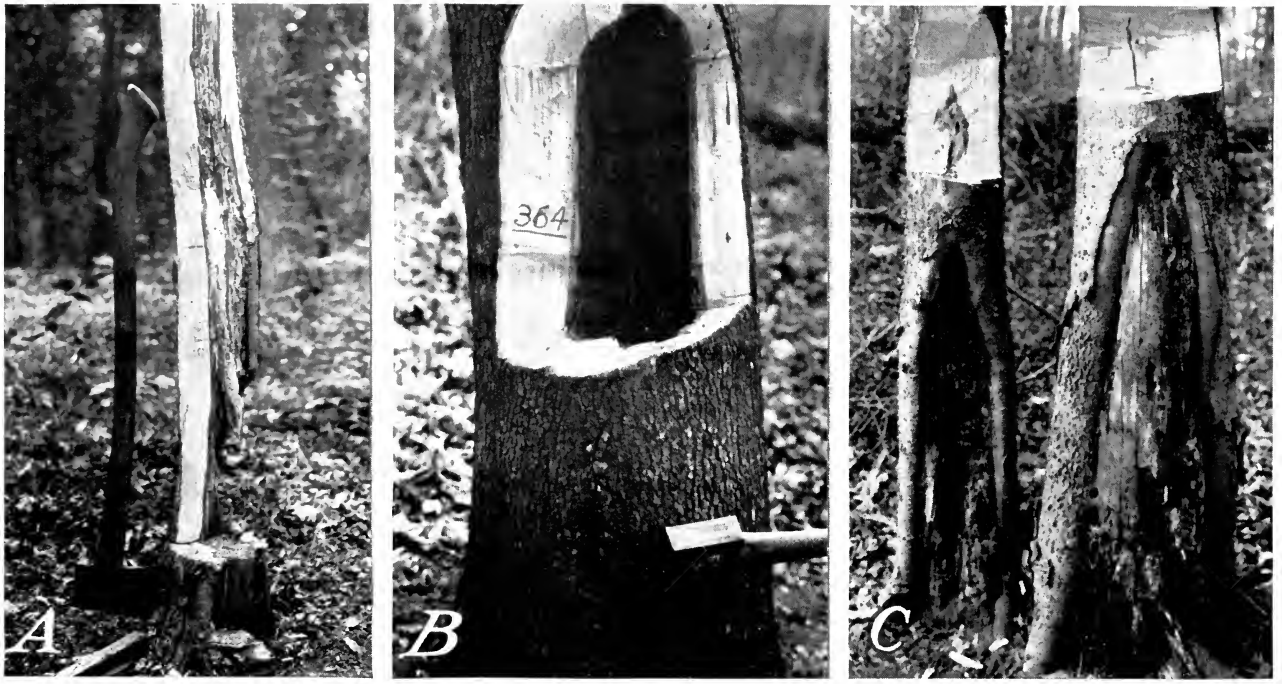


FIGURE 1.—Section from young red gum tree scarred by fire 22 years and again 15 years before photographing. Section taken 1 foot from ground. Protective zone formed over scar prevented decay and permitted healing.

The different tree genera vary greatly in their liability to infection through fire scars. Referring, in figure 2, to the well-represented scar age class 7–12 years, it is found that while 100 percent of the hackberry trees were decayed, only 53 percent of the red gum were decayed. The oaks and hackberry, when scarred, usually develop sapwood rot over the scarred area within a year after scarring, and often before the dead bark has become loosened from the wood. There is apparently little protective effect of the living sapwood beneath the killed bark, in putting up any barrier against this infection in these two genera. In red gum and persimmon, however, the living sapwood beneath the killed bark is stimulated to the formation of wound gum, which exudes into



A, A 68-year-old ash scarred 18 years and again 10 years before photographing. The center and right-hand sections are longitudinal sections of the same piece. The piece on the left is the next section above. The decay extended about 6 feet from the ground and was caused by *Lentinus tigrinus*. *B*, Ash with 33-year-old fire scar. This tree was worthless and was taking up room that might have been occupied by thrifty trees.



A, Red gum, 28 years old, scarred by fire 8 years and again 4 years before photographing. This tree was so weakened by decay (caused by *Polyporus lucidus*) that it probably would have broken over within a few years. Note sporophore at base of scar. *B*, Red gum with 19-year-old fire scar almost healed. The tree, however, is a hollow cull. (Photographed by F. H. Kaufert.) *C*, A pair of young hackberry trees with 7-year-old fire scars. Note that while the exposed portions of the butts were badly decayed the decay spread but a short distance above the scar. (Photographed by F. H. Kaufert.)

several layers of the outer xylem elements, completely filling the vessels, fibers, rays, and parenchyma cells, so that a dense hard zone is formed over the face of the scar. As long as this layer is intact infection apparently cannot take place.

Figure 1 shows a red gum tree with the dark outer protective zone that has prevented infection and drying out of the sapwood for 15 years. Such protection, however, is usually not permanent. This is partly because checks commonly form over the scar face, admitting fungus spores which presumably germinate and infect before another protective zone is laid down beneath; and partly because, if the tree is reburned, the sapwood beneath the protective zone is killed, dries out, checks, and then infection can take place readily.

Figure 2 shows that the greater the number of years since scarring, the greater is the proportion of decayed trees. Twenty years after scarring, practically all trees with open scars contained decay. The exception to this is persimmon, which is the most decay-resistant species noted. The small number of overcup oak, cherry-bark oak, willow oak, and persimmon trees analyzed does not allow much weight to be given to these species, so they are not included in figure 2. In order of susceptibility to infection, the species are: Hackberry, Nuttall oak, water oak, ash, and red gum, as shown in figure 2.

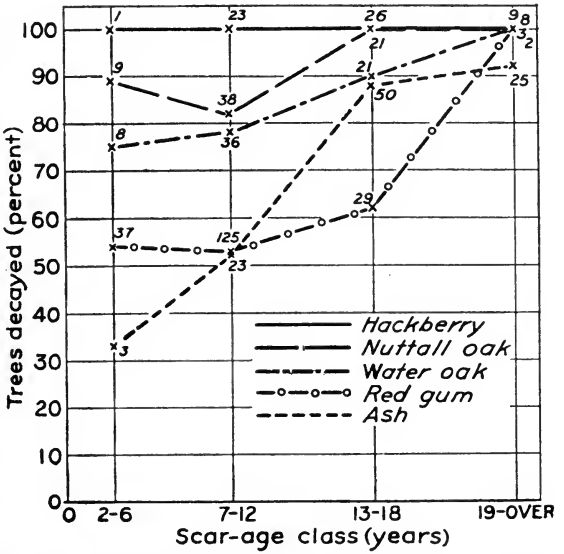


FIGURE 2.—Relation between percentage of trees decayed and years since scarring. The numbers beside the points indicate the number of trees studied in obtaining the data for the points.

The fact that only sapwood is exposed, following scarring, does not mean that serious decay will not result, or that heart rot will not develop. There are a number of facultative decay fungi in this area, which can readily attack dead sapwood, old living sapwood, or the heartwood of living trees. Two outstanding examples are *Polyporus lucidus* Fr. and *Lentinus tigrinus* (Bull.) ex Fr. As will be shown later, these two fungi attacked most of the principal tree species studied. In addition to the normally heart-rotting fungi and the facultative decay fungi, many of the more strictly saprophytic fungi, such as *Polyporus pargamenus* Fr. and *Stereum rameale* (S.) Redd., can work for some distance into the heartwood after decaying the exposed sapwood. Weir (*19*) lists 11 species of the normally saprophytic genus *Polystictus* alone, which have been found to cause

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rot in living trees. That no obligate heartwood-rotting fungus, such as *Polyporus dryophilus* Berk., was positively identified in connection with the decay in any of the trees analyzed may indicate that those fungi are not able to penetrate through the exposed sapwood, even if decayed. Referring to *P. dryophilus*, Hedgcock and Long (*6*, *p. 70*) state—"In no instance in Arkansas has the junior writer found this fungus entering a tree through fire scars, or other wounds on the butt of oaks, even where fire scars were common." Therefore those fungi which can rot both the dead and old sapwood and the heartwood of living trees with equal facility appear largely responsible for the extensive decay resulting from the scarring of young Delta hardwoods.

UPWARD SPREAD OF DECAY IN THE BOLE

Of all the various mechanical, physiological, and pathological effects of the fire-scarring of young Delta hardwoods, the most important effect, as far as the production of timber is concerned, is the reduction of the future merchantable portion of the trees through the action of wood-destroying fungi. That this infection through fire scars, with subsequent rapid spread of decay in the bole, is not confined to hardwoods is brought out by Meinecke (*15*), who states that in only 11 out of 59 fire-scarred white firs was no decay traced to the scars; and by Boyce (*1*), working in incense cedar, who states that the most serious wounds, both numerically and in regard to type of injury, result from fire. He states that as the charred face of the scar weathers away, an excellent place is offered for the entrance of wood-destroying fungi.

The upward spread of decay in trees is affected by a large number of factors. It depends upon the species of tree, the species of fungus causing the decay, the age of the tree, the diameter of the tree, the size of the fire scar, and a large number of unmeasurable factors such as climatic and site influences, extractive content of the wood and other types of tree resistance, and possibly the presence of insects and secondary fungi. It was decided, in this study, to determine the average annual upward spread of decay from fire scars, regardless of causal organism, for each well-represented tree species or species group; and then, for the black oak group and for ash, to determine the net effects of the following measurable factors on this rate: Age of tree, age of fire scar, length of fire scar, proportion of the tree circumference which had been scarred, present diameter at breast height (d. b. h.), and diameter at the time of scarring (measured on the stump). In a later section devoted to the fungi involved, differences in the rate of decay for the different fungi will be brought out.

The black oak group (which here includes Nuttall, water, willow, and cherrybark oaks) and ash were chosen for the intensive study of the effects of the six factors mentioned above, partly because these species were numerically well represented (142 black oaks and 78 ash), and partly because the rate of decay was relatively fast in those species, thereby bringing out more strongly the effects of those factors affecting the rate of decay. Only decayed trees were included in this analysis.

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The rate of decay was determined by the relation between the number of years since the trees were burned and the height of decay in the trees. The number of years since burning was determined by the number of rings on the callus folds. In red gum, overcup oak, and hackberry only the gross relation between age of fire scar and height of decay was determined, the other factors being allowed to vary as they would. In the black oak group, and in ash, however, a multiple correlation was run to determine the net relation between the age of fire scar and height of decay; and also the net effects of the five other factors already mentioned, on the rate of decay. By means of multiple correlation analysis one can determine the net effect of any one factor (for example, age of fire scar) on the factor being studied (height of decay), independent of the effects of the other related factors such as age of tree, diameter at breast height, etc. This is accomplished by holding all factors not being considered, at their mean values, while the factor under consideration (age of fire scar) is allowed to vary with the dependent factor (height of decay). The method of multiple correlation is used in the analysis of the data presented in this bulletin in part to get the most information possible from these data, and in part to test the applicability of the method as a device for studying the independent effects of each of several factors on decay.

The methods used in this correlation analysis are essentially those given by Ezekiel (*3, pp. 158–186*). Regression equations were worked out to determine the effects of the factors mentioned on height of decay in black oaks and ash. The regression equations determined are as follows:

For black oaks—

$$X_1 = -2.642 + 0.188X_2 + 0.005X_3 + 0.014X_4 + 0.003X_5 + 0.119X_6 + 0.172X_7$$

For ash—

$$X_1 = -9.221 + 0.127X_2 + 0.065X_3 - 0.004X_4 + 0.039X_5 + 0.236X_6 + 0.318X_7$$

When X_1 = height of decay
X_2 = age of fire scar
X_3 = age of tree
X_4 = length of fire scar
X_5 = percentage of circumference scarred
X_6 = present diameter at breast height (i. e. at time of examination)
X_7 = stump diameter at time of scarring.

These regression equations were then plotted. The resulting regression lines, as shown in figures 3 and 4, show how the dependent variable (height of decay) varies as each of the independent variables vary. As these regression lines were determined mathematically, the group-average deviations of the actual values from these calculated lines were also plotted, and are shown as dots about the regression lines in figures 3 and 4. In addition to the lines shown, regression lines were worked out for the relation between length of fire scar and height of decay above scar, but in both the black oaks and ash these lines were practically horizontal, indicating that no relation exists between these two factors, within the range studied,

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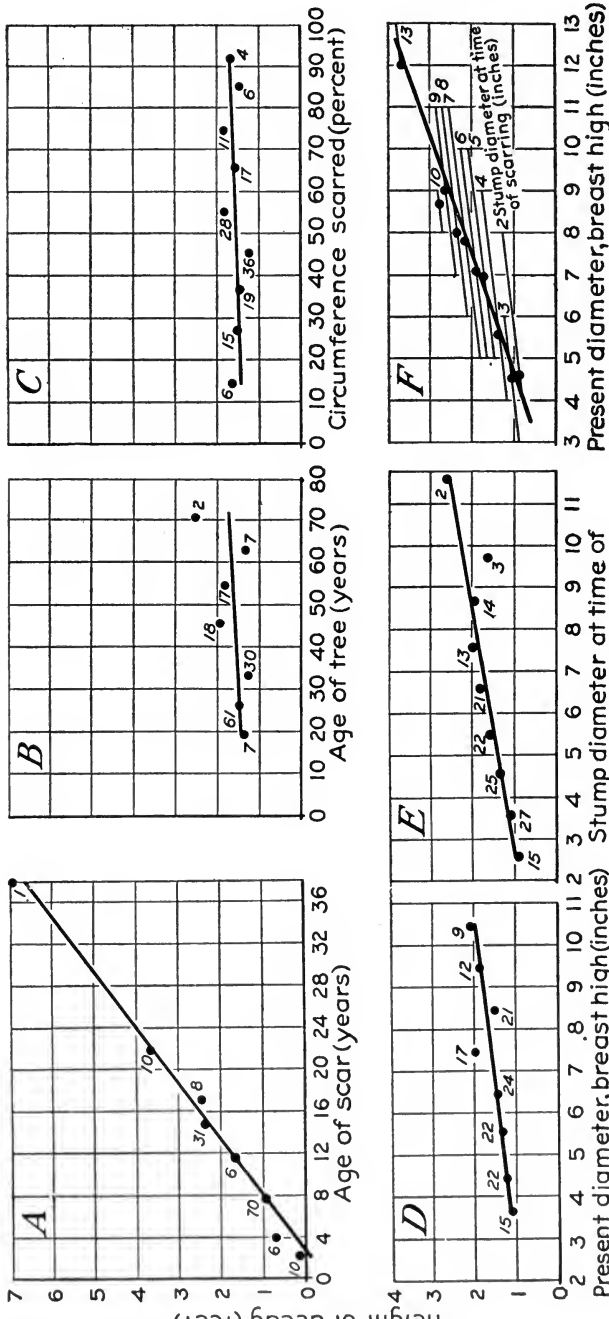

FIGURE 3.—Regression lines showing net effects of each of five factors on height of decay above fire scars in black oaks. The numbers beside the plotted points indicate the number of trees upon which each point is based. Graph F is a combination of graphs D and E. The fine lines in graph F show the decay heights with increasing present diameter at breast height, each line being for trees with the stump diameter at time of scarring that is indicated by the small figures at the right end of the line. The heavy line in graph F is the important one, showing how decay varies with present diameter at breast height when diameter at time of scarring is not held constant.

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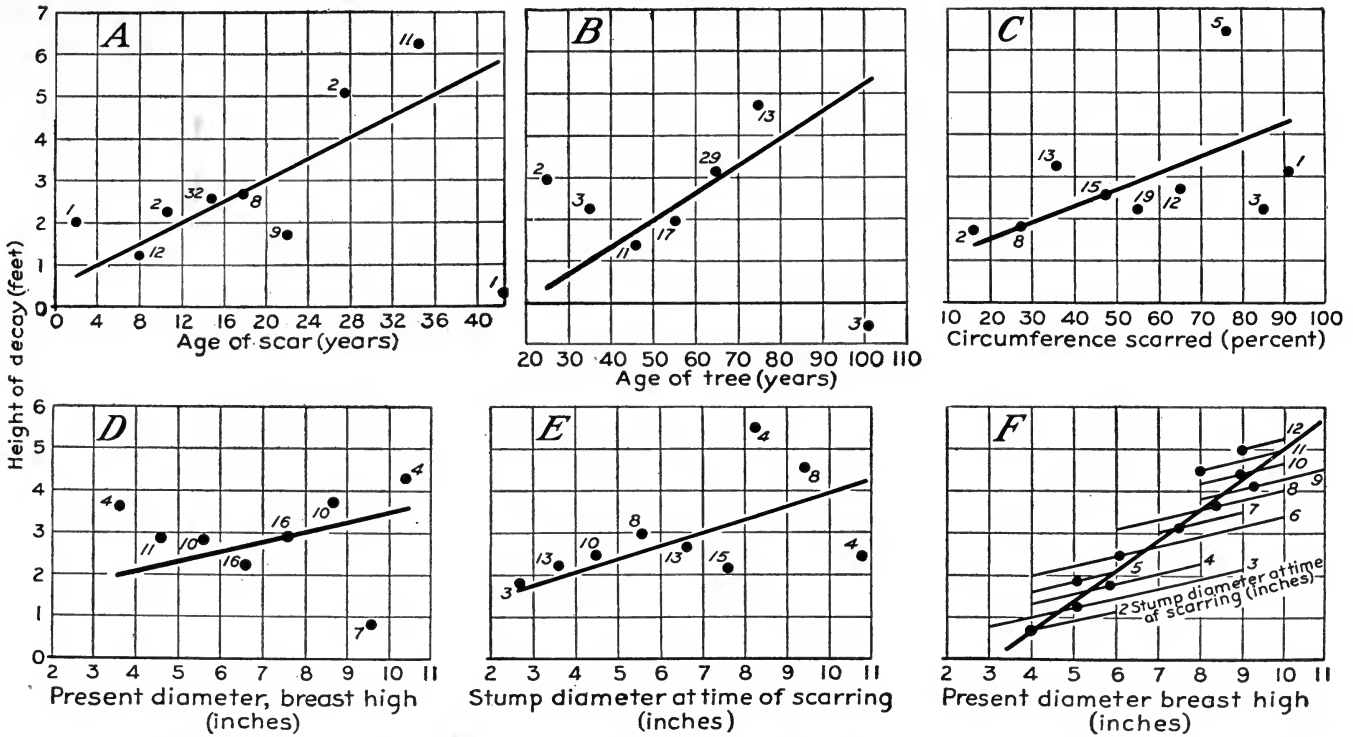

FIGURE 4.—Regression lines showing net effects of each of five factors on height of decay above fire scars in ash. The numbers beside the plotted points indicate the number of trees upon which each point is based. Graph F is a combination of graphs D and E. The fine lines in graph F show the decay heights with increasing present diameter at breast height, each line being for trees with the stump diameter at time of scarring that is indicated by the small figures at the end of the line. The heavy line in graph F is the important one, showing how decay varies with present diameter at breast height when diameter at time of scarring is not held constant.

if we assume that a straight line properly expresses any relation that might exist.

In none of the analyses of factors is there sufficient basis for assuming a curvilinear relation to exist. That is, as the age of scar, age of tree, etc., increase, the height of decay appears to increase at a constant rate. While in ash, particularly, the deviations of the actual values from the estimated are widely scattered about the regression lines, there is still no basis for assuming curvilinearity as there is an insufficient number of cases to fix the trend definitely. All are therefore assumed to be straight-line relationships. The oak regression lines, based on almost twice the number of cases as the ash, show a much closer conformity of the averaged actual values to the estimated, than do the ash.

In analyzing the graphs shown in figures 3 and 4 it must be borne in mind that in each graph, excepting graphs F, the effect of only one factor on height of decay is studied and that all the other factors are held at their average values. This statistical treatment often leads to absurdities when extremities of the regression lines are examined. For example, with the diameter at time of scarring at its mean value of 5.5 inches we can find a value for present diameter (fig. 3, graph D) of 4 inches. This is an absurdity. This condition arises out of the fact that each regression line represents only the relationship between the two factors studied, holding all others at their averages, so that each line can be interpreted literally only at that point on the line at which the other factors in the regression equation that are not represented in the given graph are at their averages. This in no way affects the value of the regression lines as indicators of relationship.

The coefficient of determination for the black oak group is 0.39, which means that 39 percent of the variance in the height of decay is ascribable to the six factors studied, namely: Age of fire scar, age of tree, length of fire scar, percentage of circumference scarred, present diameter at breast height, and stump diameter at the time of scarring. The remaining 61 percent of the variance is due to other factors not considered in this correlation, such as type of fungus causing the rot, resistance of trees, etc. The coefficient of determination for ash is 0.31. Both coefficients of determination were found to be highly significant (odds greater than 100 to 1).

RELATION BETWEEN SCAR AGE AND HEIGHT OF DECAY

There is a distinct relation between the number of years since a stand of trees was scarred and the height of decay in the trees of that stand.

DECAY IN BLACK OAKS

Figure 3, graph A, shows that in young black oaks decay spreads upward in the bole from the fire scar at an average rate of 2.3 inches per year, beginning 2 or 3 years after scarring. This figure is applicable to trees within the size range covered in this study. It means, for example, in a young stand composed of the black oaks studied, in the Delta area, 20 years after a fire the best prediction on the basis of the present data is that practically all of the trees with visible scars will contain decay (fig. 2), and the decay will have reached

an average of 3.3 feet above the scars (fig. 3, *A*). As the average height of scars for this group is 2.8 feet (table 4), there will be an average of 6.1 feet of decay in the visibly scarred trees. The decay rate of 2.3 inches per year is the average rate for all trees from 3 to 11 inches diameter at breast height, but the individual rates of decay of different trees vary as the size, age, etc., of these trees vary.

TABLE 4.—*Average values of factors considered to influence rate of decay*[1]

Tree species	Trees	Average height of decay above scar	Average scar age	Average tree age	Average scar height	Average percentage of circumference scarred	Stump diameter at time of scarring	Present diameter, breast high
	Number	*Feet*	*Years*	*Years*	*Feet*		*Inches*	*Inches*
Black oaks	142	1.5	10.8	36	2.8	50.6	5.5	6.7
Overcup oak	32	2.5	14.2	55	1.8	50.4	6.3	6.9
Red gum	104	.9	9.1	31	1.8	53.2	6.0	6.8
Ash	78	2.7	18.2	62	2.2	51.2	6.3	7.0
Hackberry	56	1.1	14.8	62	2.2	48.3	6.3	6.8

[1] Sound trees excluded.

While the figure for rate of decay has value when applied to a stand, it has little value when applied to an individual tree. For example, while the average height of decay in black oaks with 15-year-old fire scars is 2.4 feet, two-thirds of the cases lie between 0.3 foot and 4.2 feet, while one-sixth lie below and one-sixth above these limits.

In the application of the results secured in such a study as this, great care should be taken not to attempt making use of the trends beyond the limits of the data upon which the trends were established. To use the regression equations determined in this study or the graphs based on them for trees larger than 11 inches diameter at breast height would be an example of such extrapolation.

In some cases active decay apparently ceased following the rotting away of the exposed wood on the scar, and in others it ceased after working up in the bole for 2 or 3 feet. In such cases the decayed wood is usually removed by insects and secondary fungi, leaving hollows with firm walls of sound wood (pl. 2, *A*). In still other cases decay was found to have progressed several feet in the bole, with the fungus still in an active condition. Plate 2, *C*, shows an actively decaying Nuttall oak scarred in 1924. Little can be expected in the future from a young stand composed of such trees as these.

Young oaks are particularly susceptible to decay because that genus forms heartwood at an early age. The oaks of this area usually begin heartwood formation after the trees are about 15 years old, in contrast to red gum in which heartwood is usually not formed until the trees are at least 40 years old. No significant difference was noted, either in the field or in the mathematical analysis of the data, between the rates of decay in the four species of black oaks included in this study.

DECAY IN ASH

Figure 4, graph A, shows that in ash, decay spreads upward from the scar at an average rate of 1.5 inches per year. The figures on

rates of decay are based upon trees with average values as given in table 4. From figure 4, graph A, we can expect that in an ash stand in the Delta area, 20 years after scarring, the average height of decay will be 3 feet above the scars. As the scars average 2.2 feet in height there should be an average of 5.2 feet of decay in those trees. Again, while applicable to a stand, these figures cannot be applied to an individual tree. This is evident if it is noted that while the average height of decay for ash trees with 15-year-old fire scars was 2.5 feet, two-thirds of the cases fell between 0.6 foot and 4.7 feet, while a sixth were above and a sixth below these limits. There is the same wide variability in height of decay in red gum trees scarred the same length of time, while the rate of decay in hackberry and persimmon trees is much less variable. For all species the variation is much less if the tree population consists of trees of similar age and diameter.

Heartwood may form in ash any time after a tree is about 30 years old. However, the fungi which were most active in causing decay in the young trees studied (for example, *Lentinus tigrinus*) do not need heartwood to feed on, but can work up the bole equally well in a tree containing only sapwood. This is an unusual case of a parasitic sap-rot fungus. In some cases a zone of pathologic heartwood is formed in advance of the decay column. Plate 3, *A*, shows a young ash in which typical heart rot has progressed about 6 feet up from the base. This tree was scarred in 1914 and again in 1922. Notice, however, that the scar is small, and that there is no external evidence of the active decay within. Plate 3, *B*, shows the remains of an ash scarred in 1899. Such a tree is locally called a "stovepipe."

One of the working areas chosen for this study, a pure ash stand near Tallulah, La., was badly scarred in 1917. Many of the larger trees have broken over at the base, and the remaining stand is practically worthless as a result of decay following scarring.

DECAY IN OVERCUP OAK

In overcup oak, red gum, and hackberry only the gross relation between height of decay and age of fire scar is shown. Substituting the values of the independent variables for overcup oak (table 4) in the regression equation for the black oaks, it is found that if black oak had these values its height of decay would be almost the same as that found in overcup oak, indicating that the rate of decay is the same for both; that is, that decay travels upward at a rate of roughly 2.3 inches per year in all oaks studied. A graph showing the gross relation between height of decay and age of scar is given in figure 5, *A*.

Overcup oak is a notoriously defective tree in that part of the Delta south of Arkansas. It not only decays rapidly when wounded, but it is commonly riddled with large insect galleries of *Parandra brunnea* Fabr., and the wood is "shaky." Plate 2, *B*, shows a young overcup oak scarred in 1917, with active heart rot running up several feet, and with a gallery of the *Parandra*.

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DECAY IN RED GUM

Substituting the values of the independent variables for red gum, in the black oak regression equation, it is found that if black oak had these values its height of decay would be 1.3 feet, whereas the actual height of decay in red gum was 0.9 foot. This indicates that red gum decays less rapidly than oak. The gross relation between height of decay and age of fire scar, for red gum, is shown in figure

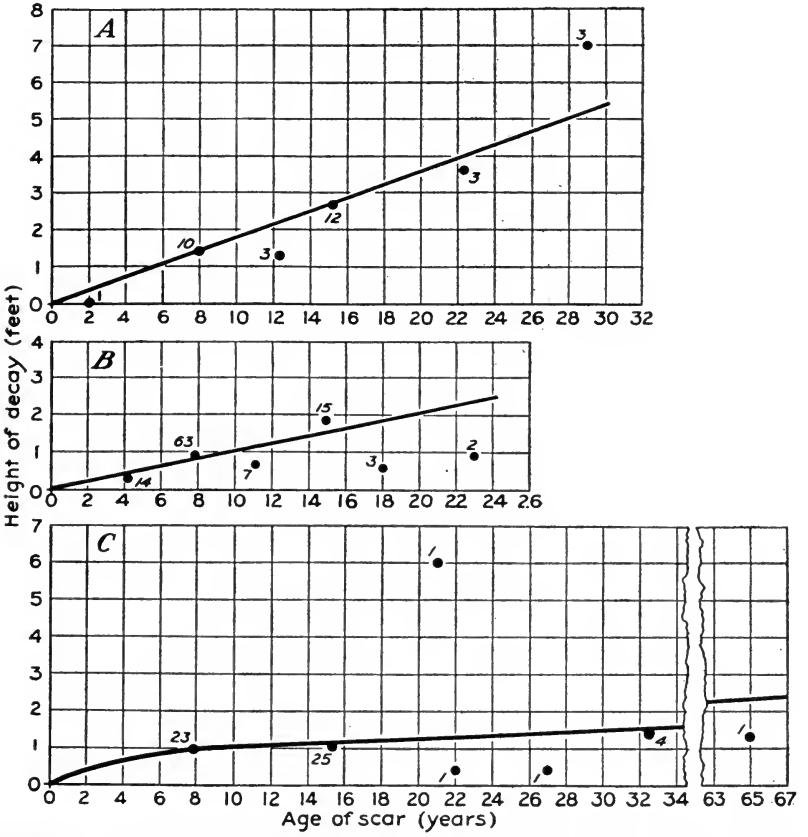

FIGURE 5.—Gross relation between age of fire scar and height of decay in overcup oak (*A*), red gum (*B*), and hackberry (*C*).

5, *B*. This graph shows that young fire-scarred red gum decays at a rate of about 1.2 inches per year.

A very small percentage of the red gum trees studied contained any normal heartwood. However, as in the case of ash, a cone of pathologic heartwood is commonly formed above the active decay, thus paving the way for the fungus if it be a heart-rotting fungus. Again, however, as in the case of ash, the important fungi can work upward in the bole, rotting only sapwood. Plate 4, *A*, shows a small red gum tree scarred in 1924 and again in 1928, in which decay caused by *Polyporus lucidus* has worked up several feet, without

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any heartwood having been present. Plate 4, *B*, shows a "stovepipe" caused by decay following fire-scarring.

An example of the effects of fire-scarring on merchantable red gum is given by Lentz (*10*). A gum stand in Pointe Coupee Parish, La., was burned in 1916 and again in 1924. The stand was cut in 1928, and there was a loss of 15 percent of the merchantable volume of the stand due to decay following those two fires.

A characteristic of decay in young Delta hardwoods that is particularly striking in red gum is that decay which sets in subsequent to fire-scarring practically confines itself to the cylinder of wood extant at the time of scarring. For example, if a gum tree is 5 inches in diameter at the time it is scarred, and composed entirely of sapwood, the decay which follows will remain confined to that 5-inch cylinder, not spreading appreciably into the sapwood layers laid down after scarring. There is, therefore, some marked difference between the sapwood extant at the time of scarring and the sapwood laid down later as to their susceptibility to decay. This difference may possibly be due to differences in the water content of the newer and older sapwood. This explanation is strengthened by the fact that the condition just described is most striking in red gum, which has a high water content when green; and least striking in ash, which when green has a lower water content than any other of the bottom-land species. In ash the decay will work out farther into the newer sapwood than in any of the other species studied. The resistance of trees to the radial spread of decay is of importance in the prevention of weakening at the butt and subsequent breaking over.

DECAY IN HACKBERRY

While hackberry is readily susceptible to infection, as shown in figure 2, the decay spreads but a very short distance upward in the bole. None of the hackberry trees studied contained any heartwood. Substituting the values of the hackberry independent variables, as given in table 4, in the black oak regression equation, it is found that if black oak had these values its height of decay would be 2.5 feet, while the average actual height of decay in hackberry was only 1.1 feet above the scar. This indicates that decay progresses much more slowly up the bole in hackberry than in the oaks. Figure 5, *C*, shows the gross relation between height of decay above scar and age of scar. It also shows a relatively rapid early rate of decay, so that the average height of decay is 1 foot at the end of 8 years. Then the rate falls off rapidly so that at the end of 32 years the decay has only spread about 6 inches farther. The small number of trees with scars older than 15 years precludes the possibility of very well establishing the curve beyond that point.

Plate 4, *C*, shows two hackberry trees with scars 7 years old. Note the badly decayed exposed sapwood and the short distance which the decay has spread into the bole.

While decay in young hackberry is of importance in weakening the bases of the trees, it appears from this study to be of little importance in causing cull in the portion of the tree above the scar, at least before heartwood formation begins.

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DECAY IN PERSIMMON

Persimmon is the soundest species studied. An examination of 18 trees with fire scars ranging in age from 2 to 27 years showed that only 50 percent were decayed. One tree was omitted because of decay having entered through a branch stub above the scar. Of the remaining 8 decayed trees, with an average scar age of 11 years, the average height of decay above the fire scar was only 0.2 foot.

RELATION BETWEEN AGE OF TREE AND RATE OF DECAY

Practically all investigators who have studied the relation between ages of trees and rate of decay, or volume of rot, have found decay to travel at a faster rate in older than in younger trees. Boyce (*1*) presents two tables showing increase in number of infections and increase in cull percentage with increase in tree age in incense cedar. While most investigators attempting to establish this relationship have worked with great ranges in tree ages (Boyce's trees ranged from less than 40 to over 440 years old), the present study on young Delta hardwoods is concerned with a very small age range, thus making any relationship between tree age and decay less striking.

Figure 3, graph B, for black oaks, shows that there is a slight increase in height of decay for increase in tree age. For the range studied there is an increase in height of decay of 3 inches for each 50-year increase in tree age. This relationship, as expressed by the regression line in graph B, for the black oaks, shows the net effect of tree age on decay height, holding all other factors considered constant at their means (table 4). Similarly, if we consider figure 4, graph B, for ash, we find an increase in the height of decay accompanying increase in tree age. While this regression line is not as well defined as the line for black oaks, it shows the same trend. The line for ash shows an increase of 3.3 feet of decay for each increase of 50 years in tree age, holding all other factors constant.

This increase in decay with increase in tree age is probably correlated with increase in heartwood formation. Yet, as will be shown later, increase in tree diameter is also accompanied by increase in decay, holding tree age constant.

RELATION BETWEEN PERCENTAGE OF TREE CIRCUMFERENCE SCARRED AND RATE OF DECAY

Instead of the degree of scarring being expressed as area of the tree scarred it is expressed here in two ways—as percentage of circumference scarred and as length of fire scar. Regression lines were plotted for the latter, as previously mentioned, but no relation was found to exist between height of decay and scar length. Figure 3, graph C, shows that for black oaks practically no relation exists between the proportion of circumference scarred and height to which the decay will run. While it is possible that a rather sharp relation might be found to exist for percentages of circumference between 1 and 10, such small scars are uncommon. This regression line indicates that once infection has taken place the size of the scar has no effect on the subsequent rate of decay. However, the situation in ash appears to be somewhat different. Figure 4, graph C, shows that in

ash there is an increase of 4.8 inches of decay for each increase of 10 percent of the circumference scarred, holding all other factors constant. While, again, the scatter of the deviations about the ash regression line is considerable, nevertheless a definite trend of relationship is established. This slightly more rapid decay in the case of the larger scars in ash may be attributed to a number of factors, such as the larger amount of initial inoculum, the better chance for aeration for the fungus involved, and others.

RELATION BETWEEN TREE DIAMETER AT TIME OF SCARRING AND RATE OF DECAY

Holding the other five factors constant, a definite relationship is found between the diameter of the tree, at the time it was scarred, as measured on the stump and the rate of decay. Figures 3 and 4, graph E, show that for black oak there is an increase of 6 inches and for ash an increase of 1 foot in the height of decay for each increase of 3 inches in diameter at the time of scarring. It must be kept in mind that this is independent of any increase in tree age. This increase in decay rate, with tree size at the time of scarring, is closely correlated with the fact brought out in the discussion on decay in red gum, that the decay column is usually confined to that portion of the bole extant at the time of scarring.

RELATION BETWEEN PRESENT DIAMETER AND RATE OF DECAY

The relation between the present diameter (breast high) and the rate of decay is not so striking as the relation between the diameter at the time of scarring and the rate of decay. This again emphasizes the greater significance, as to decay, of the wood laid down prior to scarring over the wood laid down after scarring. Figure 3, graph D, shows that in black oaks there is an increase of 6 inches of decay for each increase of 4 inches diameter at breast height, holding all the other five factors constant. Figure 4, graph D, shows that for ash there is an increase of 1 foot of decay for each increase of 4 inches in diameter at breast height. It is now seen that both the diameter of the tree at the time it was scarred and the present diameter, each independent of the other and both independent of tree age, affect the rate of upward spread of decay in black oaks and in ash.

In figures 3 and 4, graph F, original diameter, at time of scarring is allowed to vary with present diameter, as it normally does. The heavy line on each graph expresses the total effect of diameter variation upon decay rate, holding the other four factors constant. These lines show that for black oak there is an increase of 1 foot of decay for each increase of 3 inches in diameter, while for ash there is an increase of 1 foot of decay for each increase of 1.4 inches of diameter for trees of equal age and scar age.

In the past it has been common to attribute the relation between diameter and decay to the relation of diameter to tree age and amount of heartwood present. The above figures show, however, a decided relation between diameter and rate of decay, even when age is held constant, and that this relationship holds in a species such as ash, the great majority of the trees of which contained no heartwood.

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RELATION BETWEEN RATE OF DIAMETER GROWTH AND RATE OF DECAY

In studying the relationships of age of tree to height of decay holding diameter at a constant value, and diameter of tree to height of decay holding tree age constant, the growth rate must of necessity vary. It may therefore be logical to suppose that the apparent net relationship of age or diameter to height of decay as shown in the regression graphs is in reality a relationship of rate of growth to decay. However, if rate of growth is considered the more important factor determining decay rate, it is found that graphs B and F in each of figures 3 and 4 contradict each other. In graph B, showing the relation between tree age and decay, the less vigorous trees would be found to decay more rapidly, while in graph F, showing the relation between diameter and decay, the more vigorous would be found to decay more rapidly. Since such a conclusion is impossible, it seems likely that vigor, as measured by rate of diameter growth, was not an important factor. If rate of diameter growth were closely correlated with decay, graphs B and F would tend to balance each other and the regression lines would be more nearly horizontal.

The direct effect of rate of diameter growth on decay rate was studied for black oaks with 8-year-old scars and for those with 15-year-old scars. Graphs were prepared with height of decay as the ordinate and rate of diameter growth, expressed as the ratio of diameter to age, as the abscissa. The actual decay-height values were plotted. The line of best fit for the 8-year-old scars sloped slightly upward and the line for the 15-year-old scars sloped slightly downward. No definite relation between decay and rate of diameter growth could be established. It thus appears that rate of growth is not significantly correlated with decay and that the relationships determined between tree age and decay and between diameter and decay are dependent not on rate of growth but on some other conditions in the wood. For example, the decay fungi may be favored by access to a large core of wood of high age, or to wood remote from the active cambial zone.

EFFECTS OF CERTAIN UNMEASURABLE FACTORS ON DECAY RATE

The regression analyses involved the study of several measurable factors suspected of affecting the rate of decay. There are a number of other possibly influential variables that are not quantitatively measurable. For example, is decay more rapid in trees on which the scars reach the ground? Is the decay rate appreciably different in the four parts of the Delta where the work was done? Having once developed the regression equation these unmeasurable factors can be studied as shown in the following example.

The effect on decay rate of the scar reaching the ground was studied for black oaks and for ash. By substituting the values for the independent variables in the regression equations or by using alinement charts, it is possible to arrive at a figure for height of decay in each tree. These may be called the estimated values. The actual heights of decay in the trees are also determined. The difference between the two values for a given tree is called the error of estimate. The next step is to separate the trees into two groups, de-

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pending on whether or not the scars reach the ground. The average deviation of the actual from the estimated for each group is next determined. If those trees with scars reaching the ground decayed faster than the other group then their actual values for decay height would fall significantly above the estimated, and the actual values for those with scars not reaching the ground would fall below the estimated. This allows a fair comparison of the two lots of trees even though they may differ significantly in some of the measurable factors, such as scar age, which affect height of decay. In ash, the average of the actual values for height of decay in the trees with scars reaching the ground was 0.31 foot below the estimated values. The average of the actual values for those with scars not reaching ground was 0.59 foot above the estimated. This is a difference of 0.9 foot. The standard error is 0.72 foot. In black oaks, the average of the actual values for height of decay in trees with scars reaching ground was 0.14 foot above the estimated. The average of the actual values for those with scars not reaching ground was 0.16 foot below the estimated. Thus ash and oak are contradictory as to the relationship they indicate between the decay height and the scar reaching ground. In both ash and oak, however, the difference in decay height between the trees with scars reaching and not reaching ground is not mathematically significant.

In a manner similar to that just described, the relation between decay rate and the different parts of the Delta sampled was studied for black oaks and ash. The plus and minus deviations of the actual values from the estimated were computed. Little difference appeared between the rates of decay at Lake Providence, La., Opelousas, La., Rolling Fork, Miss., and Batesville, Miss., or between the percentage of scarred trees decayed at these places. This does not mean, however, that there is necessarily no actual difference in decay rates in different parts of the Delta because the number of trees used as a basis, in each locality, was small. There was some indication that decay progressed somewhat more slowly at the northernmost study area (Batesville, Miss.) than at the other localities. (See table 7.)

The fungi causing the decays represent an unmeasurable factor affecting decay rate. Their effect is analyzed later in this bulletin.

IMPORTANCE OF FIRE SCARS IN CAUSING BREAKING-OVER

A large proportion of the young second-growth hardwood stands in the Mississippi Delta are considerably understocked. In seeking the reason for this understocking, it was apparent early that fire was largely responsible. The effect of fire in causing this understocking can be divided into three principal headings: (1) The complete consumption of seedlings and small saplings, (2) the girdling of saplings and poles, and (3) the weakening of the bases of young trees through decay entering through fire scars. This study deals only with the last of these headings and the process is here referred to as "rotting down." Plate 1 illustrates this process.

In order to determine the significance of the rotting down of young fire-scarred trees, all trees that had fallen from this cause within the last 2 or 3 years were sought wherever they could be found. The object was (1) to determine how common in occurrence the process

is, and (2) to determine what set of conditions cause the trees to fall. Only recently fallen trees and trees that were still alive were counted and analyzed. These qualifications were essential because fallen material decays so rapidly in this area that if attempts were made to analyze trees down longer than 2 or 3 years, or dead trees, it would be impossible to separate the decay that set in after falling from the decay that began in the trees while they were still standing. Hence it would not be possible to ascertain the conditions within that caused the tree to fall. The exclusion of the dead trees has but little effect on the data, however, as the great majority of fallen trees were still alive several years after falling. They remain alive because of the continued functioning of the unscarred portion of the phloem tissues in the transfer of food and nutrients, and because a portion of the sapwood usually remains unbroken, even after the trees are prostrate.

In the 20 areas on which this study was conducted, only 28 trees were found, within the diameter at breast height limits of 3 and 11 inches and still alive, which had fallen within the past 3 years because of decay following fire-scarring. Sixty-one percent of these trees were red gum, 25 percent were hackberry, and 14 percent were various oaks. No ash or persimmon within these diameter limits was found to have fallen from this cause. With but few exceptions, the trees that had broken over were either suppressed trees or trees that had crowns in poor condition. Of the fallen trees, 64 percent had been overtopped, 32 percent had been intermediates, and 4 percent had been codominants; while of the standing trees of these species that were analyzed only 34 percent were overtopped, 32 percent were intermediates, and 34 percent were codominants and dominants. The former crown classes of the fallen trees were determined by comparing the lengths of the down trees with the heights of the trees with which they had been in association. The fallen trees were analyzed in the same manner as were the standing trees.

The fallen trees had an average scar age of 8 years, an average stump diameter of 6 inches when scarred, and an average of 70 percent of original circumference scarred (table 5). The average percentage of circumference scarred of standing trees was 49. Twenty-five standing trees were found, from the data sheets, to be comparable to the 28 fallen trees, as described in table 5. These two groups were then compared to determine the reason why the fallen trees broke over. Table 5 shows that a somewhat larger proportion of the basal area (area extant at time of scarring) was decayed in the case of the fallen trees than in the standing trees; but the most significant difference lies in the quantities of wood laid down after scarring, in the two groups. This table shows that while the standing trees had added an average of 120 percent to their basal areas in the 8 years following scarring, the fallen trees had added only 41 percent in the same length of time. This shows that, all other things being equal, the fallen trees broke over primarily because their rate of diameter growth was not rapid enough to offset the rate of decay in the butts. This is consistent with the fact that 64 percent of these trees were overtopped. The low average scar age of the fallen trees is in part caused by the severe and extensive fires of

1924–25; but it also indicates that trees that do not rot down within 10 years after scarring are not likely to go down subsequently.

TABLE 5.—*Comparison of fallen with comparable standing trees, showing cause of falling* [1]

Description	Cases	Average percent original basal area decayed [2]	Average percent increase over original basal area [2]	Red gum	Hackberry	Oaks
	Number			*Percent*	*Percent*	*Percent*
Standing	25	68	120	56	12	32
Fallen	28	83	41	61	25	14

[1] Both fallen and standing trees have an average scar age of 8 years, had stump diameters of 6 inches when scarred, and an average of 70 percent of original circumference scarred.
[2] At time of scarring.

That this breaking over in these young stands is not a prevalent process, and tends to remove chiefly the overtopped trees and trees in poor condition of vigor, makes the process of doubtful harm, and possibly it may be a benefit by removing undesirable individuals. Ordinarily, regardless of how badly a young tree is scarred, in this region of rapid growth it will put on wood rapidly enough to remain in the stand, in spite of decay. Badly scarred trees thus remaining in the stand, which will have little or no merchantable value in the future, simply take up space that might be occupied by young healthy timber. The conclusions drawn here on the significance of the rotting down of young scarred trees is in close agreement with those drawn by Kaufert (*7*) for the same region. Kaufert (*7*, *p. 67*) states:

> This process takes place to some extent in many of the immature stands of the Delta. However, the understocking on many areas appears to be due primarily to direct killing of reproduction rather than to the falling over of immature trees that have been weakened by fire and decay.

It must be borne in mind that the results of this study are applicable only to timber in the diameter range studied. Field observations in fire-scarred timber of merchantable size indicated that breaking at or near the ground level was of more common occurrence than in young timber.

EFFECT OF REPEATED SCARRING ON DECAY IN RED GUM

In order to determine the effect of repeated burning on decay, the species best represented numerically, red gum, was selected. The trees were separated into two groups: Those scarred but once, in 1924, and those scarred in 1924 and one or more times since that year. These two groups were then compared as to the percentage of trees decayed and the percentage that were sound. Table 6 shows the results of this comparison. Forty-two percent of the once-scarred trees were decayed when cut in 1932, while 79 percent, or nearly double the percentage, of repeatedly scarred trees were decayed by that year. Basing the significance of this difference on the

number of trees analyzed, the odds are greater than 1,000 to 1 (χ^2 test) that repeatedly scarred trees are more susceptible to decay than are once-scarred trees.

The reason for this greater susceptibility of reburned red gum trees to decay is probably due to the killing of the sapwood exposed by the first fire, with its subsequent drying out and checking. As stated earlier, for this species, as long as the outer exposed sapwood remains alive, a protective barrier of gum-filled cells is put up against infection. If this sapwood is killed, however, as in repeated burning, it decays readily. This increase in susceptibility to decay of reburned trees is of prime importance probably only in those trees that form a protective layer, such as red gum and persimmon. In such species as the oaks and hackberry, decay of the sapwood usually begins soon after a single fire. In some cases portions of the previously exposed sapwood are burned away by subsequent fires, although this is not common in young timber in the Delta.

TABLE 6.—*Comparison of once-scarred with repeatedly scarred red gum as to susceptibility to decay*

Description [1]	Decayed in 1932		Sound in 1932	
	Number	*Percent*	*Number*	*Percent*
Once-scarred trees	36	42	49	58
Repeatedly scarred trees [2]	23	79	6	21

[1] Once-scarred trees were scarred only in 1924. Repeatedly scarred trees were scarred in 1924 and one or more times since.

[2] Odds are greater than 1,000 to 1 that repeatedly scarred trees are more susceptible to decay than once-scarred trees. Odds determined by χ^2 test.

THE FUNGI

Because sporophores of fungi were so rarely found in connection with decay behind fire scars, and because the decays of hardwoods in the Delta area are so imperfectly known, it was apparent at the start of this study that the only means of determining definitely the fungi causing the decays would be by preparing cultures. However, so little progress has been made, up to the present time, in the determination of wood-destroying fungi on a basis of cultural characteristics that the method has distinct limitations. Fritz (*4*) studied several northern wood-destroying fungi in culture, and provides a key for their separation on a basis of cultural characteristics; and Long and Harsch (*14*) describe methods for the study of wood-destroying fungi in culture, with emphasis on methods of securing artificial sporophore production. Little information is available that would serve to distinguish wood-destroying fungi in pure culture other than the few kinds described in these two papers.

In the time allowed for this investigation, it was not possible to go into a detailed study of the microscopic and physiologic characters, in culture, of the large number of wood-decay fungi found in the Delta area. The determinations of fungi which were found to cause decay behind fire scars were made by comparing, on a basis of macroscopic characters, the unknown cultures made from isolations from the decayed wood, with known cultures made from sporophores collected in the area. In this way it was possible to determine

definitely many of the important fungi, and to group many others which appeared to be similar.

Two cultures were made from every tree containing typical decay. The methods have already been described. The cultures were permitted to get a good start and were then sent to Washington, D. C., where transfers were made for study. Cultures were prepared from 251 of the 429 decayed trees. Of these 251 trees, 171 yielded apparently pure cultures of decay fungi, 52 yielded cultures which were obviously contaminated, and 28 yielded no organisms whatsoever. The principal contaminants from the wood were *Trichoderma* spp., *Torula* spp., *Penicillium* spp., and various bacteria.

In only 2 cases out of the 171 sets of successful cultures did the 2 cultures taken from the same tree yield 2 different hymenomycetous fungi. This brings out the fact that, in the trees analyzed, but one fungus is responsible for the major decay in any one tree.

In table 7 are listed the fungi determined in connection with the decays, the host trees, the average scar age of the trees in which they were found, and the average height of decay in those trees. The table clearly indicates the nature of part of the 61 percent of variance of decay in black oaks and of the 69 percent in ash, unaccounted for by the six factors studied in the correlation analysis of height of decay. Table 7 shows that the height to which decay will progress depends, to a considerable degree, upon the fungus causing the decay. For example, *Hydnum erinaceus* (Bull.) Fr. was found to have progressed an average of 6.7 feet above the fire scars, with an average scar age of 23 years. The unidentified yellow hymenomycete found only in overcup oak is also capable of active decay many years after scarring, and it progressed almost as fast as *H. erinaceus*. On the other hand, *Fomes geotropus* Cke., which was the fungus the writer most commonly isolated, was found to have progressed an average of only 2 feet above the fire scars, with an average scar age of 11 years. The fungi least capable of spreading beyond the exposed wood into the boles of the trees were species of *Stereum*, *Polyporus pargamenus* Fr., and *Coprinus radians* (Desm.) Fr.

The Stereums listed and *Polyporus pargamenus* Fr., which are essentially saprophytic decay fungi, practically confine their activity to the exposed wood of newly formed scars. When this sapwood has been decomposed, the activity of these fungi usually ceases. There may be no further decay activity, in which case little damage will result to the tree; or it is possible that certain more potent wood-destroying fungi can follow these sapwood rotters, causing active trunk rot.

Table 7 shows that a great variety of hymenomycetous fungi are involved in decay behind these fire scars, and that agarics play a major role. *Lentinus tigrinus*, one of the most important tree-decay fungi in the Delta area, has been isolated from decayed wood as far as 9 feet above a fire scar, and *Pleurotus ostreatus* has been isolated from as far as 5 feet above a fire scar.

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TABLE 7.—*Fungi determined in connection with fire-scar decay*

[Composed of data taken in connection with the study described in this bulletin and data taken by F. H. Kaufert in connection with a similar study made in the Mississippi Delta in 1931]

Fungus species [1]	Where found [2]				Cases in—					Total	Average scar age	Average height decay above scar	Average annual rate of decay
	A	B	C	D	Red gum	Ash	Black oak group	Overcup oak	Hackberry				
Hydnum erinaceus (Bull.) Fr.	2	3	1	1	*No.* 0	*No.* 0	*No.* 5	*No.* 2	*No.* 0	*No.* 7	*Years* 23	*Feet* 6.7	*Inches* 3.5
Yellow hymenomycete	3	0	4	0	0	0	0	7	0	7	14	3.6	3.1
Polyporus lucidus (Leyss.) Fr.	10	2	4	0	4	1	10	0	1	16	8	2.0	3.0
Polyporus fissilis Berk. and Curt	3	1	0	0	1	0	2	1	0	4	13	3.0	2.8
Pleurotus ostreatus (Jacq.) Fr.	5	1	4	4	7	2	5	0	0	14	9	1.9	2.5
Lentinus tigrinus (Bull.) Fr.	26	3	14	0	5	28	3	7	0	43	15	3.0	2.4
White hymenomycete I	3	1	1	1	0	1	3	2	0	6	14	2.6	2.3
White hymenomycete II	0	1	2	1	3	0	1	0	0	4	11	2.0	2.2
Fomes geotropus Cke	26	7	6	0	8	11	16	2	2	39	11	2.0	2.0
Polyporus zonalis Berk	3	2	0	0	1	1	1	1	1	5	12	1.9	1.9

[1] Weakly or nonparasitic fungi found causing decay behind fire scars, but extending little or not at all above the scars: *Polyporus distortus* (Schw.) Fr., *P. pargamenus* Fr., *P. supinus* (Sw.) Fr., *Stereum rameale* Schw., *S. ochraceo-flavum* Schw., *Armillaria mellea*, *Coprinus radians*. Sixty isolations in the present study could not be determined.

[2] A, Northeastern Louisiana; B, vicinity of Opelousas, La.; C, vicinity of Rolling Fork, Miss.; D, vicinity of Batesville, Miss.

No attempt will be made here to describe in detail the cultural characteristics of the fungi listed in table 7. However, the principal criteria in the determination of the more important fungi follow: *Hydnum erinaceus* has a white mycelium which produces numerous corallike protrusions. *Lentinus tigrinus* has a white mycelium with the surface and aerial hyphae turning dark brown or black with age, and always forms small but perfect sporophores if left in the light (fig. 6). *Polyporus fissilis* has a white, coarse mycelium which grows slowly, often forming a thick tuft around the inoculum before reaching the edge of the agar. *P. lucidus* has a white mycelium which produces no aerial hyphae but forms a flat mat with a distinctly chalky surface which may be white or yellowish in color. *Pleurotus ostreatus* produces a white, light cottony mycelium with an abundance of aerial hyphae and sometimes small abortive sporophores. *Fomes geotropus* has a white mycelium which adheres closely to the agar, somewhat similar to *Polyporus lucidus*, and which produces small lamellate fruiting bodies where the agar comes in contact with the test tube. *P. zonalis* has a white mycelium which sends characteristic white hyphal strands (not rhizomorphs) straight down into the agar from the surface. *P. supinus* has a white mycelium with no definite macroscopic characteristics for its differentiation, and was identified by the presence of sporophores on the tree. *P. distortus* has a pinkish-white mycelium which produces small, typical, pink, somewhat daedaloid sporophores where the agar comes in contact with the tube. *Armillaria mellea* has a pale-brown mycelium with a very scant surface growth, no aerial hyphae, and thick brown rhizomorphs which branch and penetrate deeply into the agar. *Stereum rameale* and *S. ochraceo-flavum* have light-brown mycelium with a dense cottony hyphal

growth over the surface of the agar, and were identified and separated by the presence of sporophores on the wood. *Polyporus pargamenus* has a white mycelium with scant and patchy surface growth and no aerial hyphae. *Coprinus radians* has a brown mycelium, and the one culture obtained produced a tall perfect fruiting body which deliquesced soon after forming, leaving an abundance of spores over the hyphal mat and along the sides of the tube.

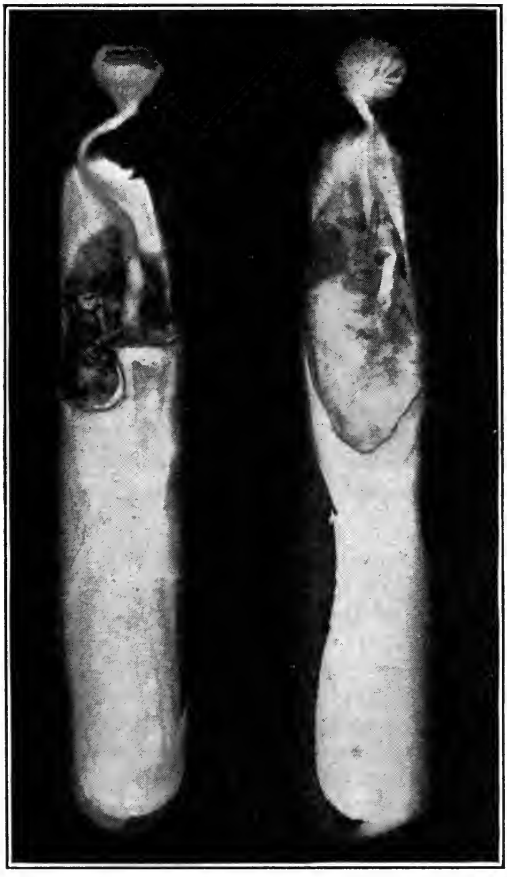

FIGURE 6.—Two cultures of *Lentinus tigrinus* showing dark-colored surface mycelium and sporophores.

INSECT DAMAGE

Fire-scarring, in addition to exposing trees to fungus infection, also leaves them open to insect attack. In an attempt to determine the importance of insect invasion through fire scars in young Delta hardwoods, all insects and insect damage, and the region of activity of the insects (whether in decayed or sound wood) were noted. Wherever insect activity was found, it was associated with decay. Out of 173 sound fire-scarred trees none showed any insect activity in the wood behind the scars. However, referring to table 8, 335, or 78 percent, of the decayed trees were or had been infested with insects. Insect activity was determined by the presence of the insects, by galleries of various sorts, or by the etched walls of hollows in the trees. Table 8 shows that the decayed wood of all species of trees studied is highly susceptible to insect attack, the most readily infested species being hackberry.

TABLE 8.—*Insect infestation of fire-scarred trees of different species*[1]

Species	Decayed trees	Decayed trees infested		Species	Decayed trees	Decayed trees infested	
	Number	*Number*	*Percent*		*Number*	*Number*	*Percent*
Hackberry	59	55	93	Red gum	106	81	76
Cherrybark oak	9	8	89	Nuttall oak	68	51	75
Willow oak	9	8	89	Water oak	56	38	68
Persimmon	9	7	78				
Ash	80	62	77	Total	429	335	78
Overcup oak	33	25	76				

[1] Trees classed as "infested" include those in which insects were found to be working in the wood and those in which evidence of their activity only remained. No sound tree was found to be infested.

INSECTS COLLECTED BEHIND FIRE SCARS

As might be expected, a large variety of insects were found to inhabit the decayed and adjacent sound wood in fire-scarred trees. Table 9 lists the insects collected, with their host trees. It is apparent from this table that the insects most commonly found were ants and termites, followed in frequency of occurrence by certain tenebrionid beetles and their larvae, a passalid beetle, and a cerambycid beetle. An assortment of other coleopterous insects were found, which are, for the most part, general invaders of any partially decomposed wood, and of little economic importance.

TABLE 9.—*Distribution of insects behind fire scars, by tree genera*

[All insects are adults unless otherwise noted]

Insect	Trees infested					
	Red gum	Oaks	Ash	Hackberry	Persimmon	Total
Hymenoptera:						
Formicidae—	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*
Crematogaster sp.	21	14	6	11	2	54
C. victima F. Smith	0	0	1	0	0	1
Monomorium pharaonis L	0	0	0	2	0	2
M. minutum minimum Buck	2	2	0	0	0	4
Pheidole sp.	3	3	1	1	0	8
Aphaenogaster fulva Roger	0	4	0	0	0	4
A. tennesseensis Mayr	0	1	0	0	0	1
Camponotus herculeanus pennsylvanicus DeG.	0	3	2	0	0	5
C. caryae Fitch	1	0	0	0	0	1
Camponotus sp.	1	0	0	0	0	1
Ponera coarctata pennsylvanicus Buck	0	0	1	0	0	1
Pseudomyrma sp.	0	0	1	0	0	1
Isoptera:						
Rhinotermitidae—						
Reticulitermes flavipes Kol	4	2	0	0	0	6
R. virginicus Bks.	0	1	0	0	2	3
Reticulitermes sp.	12	8	2	6	1	29
Kalotermitidae—						
Kalotermes approximatus Say	0	0	0	1	0	1
Coleoptera:						
Passalidae—						
Passalus cornutus Fab.	2	2	4	0	0	8
Tenebrionidae—						
Alobates pennsylvanicus DeG.	4	[1] 12	1	1	0	18
Strongylium tenuicolle Say	3	1	1	2	0	[2] 7
S. terminatum Say (near)	2	1	0	4	0	7
Xylopinus sp.	0	3	1	0	0	[2] 4
Carabidae—						
Chlaenius erythropus Dej.	5	1	0	0	0	6
Galerita bicolor Drury	0	1	0	0	0	1
Lophoglossus haldemani Lec.	1	0	0	0	0	1
Brachynus sp.	1	0	0	0	0	1
Cerambycidae—						
Parandra brunnea Fabr.	4	3	1	0	0	[2] 8
Malladon dasystomus Say	1	0	1	0	0	[2] 2
Elateridae—						
Melanotus fissilis Say	1	0	0	0	0	1
M. sp.	0	0	0	1	0	1
Orthostethus infuscatus Germ.	1	0	0	0	0	1
Melanactes puncticollis Lec.	1	0	0	0	0	1
Scarabeidae—						
Valgus sp.	0	0	1	0	0	[2] 1
Ligyrus or *Eutheola*	0	1	0	0	0	[2] 1
Cleridae—						
Priocera castanea Newm.	0	0	0	1	0	[2] 1
Curculionidae—						
Pseudopentarthrum robustum Csy.	0	0	0	1	0	1
Erotylidae—						
Megalodachne fasciata Fabr.	0	1	0	0	0	1
Diptera:						
Phoridae—						
Megaselia sp.	1	0	0	0	0	1
Lepidoptera:						
Noctuidae—						
Epizeuxis lubricalis Gey. (?)	0	1	0	0	0	1

[1] 1 larva, [2] All larvae.

A member of the genus *Crematogaster* was the most commonly found ant. This insect was found to feed both in the decayed wood and in the sound wood immediately beyond the decay column. Its galleries were never found to extend more than a few centimeters into the sound wood. This insect, along with the termites, is responsible for much of the hollowing out of the decayed trees, but practically confines its activity to decayed material. In most species of trees the nests are diffused through the decayed wood, but in hackberry, in which the decayed wood is removed as it is formed, the nest is at the top of the hollow, the ants feeding on the wood as it decays. Another member of this genus, *C. lineolata*, is mentioned by Comstock (*2, p. 943*) as commonly inhabiting decayed logs and stumps in northeastern United States and Canada.

Termites occurred almost as frequently as ants and are often found working behind the same scar. Species of the subterranean genus *Reticulitermes* were by far the most commonly observed, although a species of the nonsubterranean genus *Kalotermes* was also collected. The habits of these termites are well described by Snyder (*18, pp. 1–5*). He states, "Subterranean termites live in forests, building their nests in the wood of standing timber, logs, or stumps, any wood in contact with the ground, ..." While Snyder states that these subterranean forms will attack wood directly, usually eating out the spring wood, following the grain, they were found, in this study, to practically confine their feeding to decayed wood, never extending their galleries more than a few centimeters beyond the decayed portion. The feeding habits of the worker class of the *Reticulitermes* were similar to those of the *Crematogaster* mentioned above. Termite galleries could usually be readily distinguished from ant galleries by the presence of earthen linings. As neither the ants nor the termites appeared to extend their feeding very far into sound wood, they are regarded as having done little damage to the trees in which they occurred. Within a few years after active decay ceased, the trees were found to be forsaken by the ants and termites. It was unusual to find ants or termites in trees with fire scars older than about 10 years, while in trees with younger scars active colonies were present in most cases.

The adult beetles of *Passalus cornutus* and *Alobates pennsylvanicus* were found boring large tortuous galleries through the decayed wood. They were not observed in sound wood. The larvae of *Strongylium tenuicolle* and *S. terminatum* were also found only in decayed wood. Of all the insects observed and collected, the only species which penetrated more than a few centimeters into apparently sound wood was the cerambycid *Parandra brunnea*, already mentioned in connection with decay in overcup oak. In all cases in which larvae of this insect were found, they had formed galleries running several inches into the sound wood above the decayed portion. This insect is of considerable importance in causing defects in standing hardwood timber in this area, particularly in overcup oak and red gum. Snyder (*17, p. 21*) shows photographs of grub holes formed by this insect in overcup oak.

While fire-scarred hardwoods are constantly subject to the attack of insects, in the young fire-scarred Delta hardwoods included in the present study, insects were secondary in importance to fungi, and

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were playing a minor role in the cull that was developing in the butts as a result of the scarring.

SUMMARY

During the summer and fall of 1932, 602 fire-scarred trees of 9 species of Delta hardwoods were dissected and analyzed for decay and insect activity. The trees were between 3 and 11 inches in diameter, and were taken from 4 parishes in Louisiana and 3 counties in Mississippi.

Forest fires have been of frequent occurrence in the Mississippi Delta area at least for the past 30 years, with the fire seasons 1917–18 and 1924–25 outstanding in severity of damage done during those seasons.

Fire scars healed most rapidly in the oaks and red gum, followed by ash, hackberry, and persimmon.

The greater the number of years since scarring, the greater the proportion of scarred trees decayed. Of the species studied, hackberry was found to be the most susceptible to initial infection, followed by the oaks, ash, red gum, and persimmon.

Following scarring, in red gum and persimmon, wound gum is produced just under the scarred surface, which protects the trees against infection. Much of this protective effect is lost, if subsequent fires kill the exposed sapwood.

Decay spread upward from the fire scar most rapidly in the oaks (2.3 inches per year), followed in order by ash, red gum, hackberry, and persimmon.

A definite relation was found between the rate of decay and each of the following factors: Age of tree, percentage of tree circumference scarred, diameter at the time of scarring, present diameter, and fungus causing the decay.

The breaking-over of young trees at the base, because of decay following fire-scarring, was found to be of infrequent occurrence and chiefly confined to overtopped trees and trees otherwise in poor vigor.

A large number of fungi, from several families of the Hymenomycetes, were found to cause decay behind fire scars in the Delta area. Many of these fungi, including *Lentinus tigrinus* and *Polyporus lucidus*, can rot dead sapwood, old sapwood of living trees, and the heartwood of living trees. But one fungus in any one tree was responsible for the major decay.

A large variety of insects, chief among which are ants and termites, invade the decayed wood behind fire scars in this area. Only one insect, *Parandra brunnea*, was found to invade the sound wood beyond the decay column for any distance. Insects appeared to play a minor role in the ultimate damage.

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TECHNICAL BULLETIN No. 493 JANUARY 1936

FARM PRICES OF COTTON RELATED TO ITS GRADE AND STAPLE LENGTH IN THE UNITED STATES, SEASONS 1928–29 TO 1932–33

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UNITED STATES DEPARTMENT OF AGRICULTURE, WASHINGTON, D. C.
IN COOPERATION WITH
STATE AGRICULTURAL EXPERIMENT STATIONS OF THE COTTON BELT

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UNITED STATES DEPARTMENT OF AGRICULTURE
WASHINGTON, D. C.

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By L. D. HOWELL, *senior agricultural economist,* and JOHN S. BURGESS, Jr., *assistant agricultural economist, Division of Cotton Marketing, Bureau of Agricultural Economics* [1]

The Bureau of Agricultural Economics in Cooperation With the Agricultural Experiment Stations of Alabama, Arkansas, Florida, Georgia, Louisiana, Mississippi, North Carolina, Oklahoma, South Carolina, Tennessee, and Texas

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INTRODUCTION

Cotton farmers in the United States have been urged repeatedly to improve the quality of the cotton produced. Especial emphasis has been given to the importance of growing longer staple varieties. Farmers in many localities have been advised that these varieties are more profitable than shorter staple varieties. Although it has been generally recognized that higher grade and longer staple cottons are more valuable for spinning purposes than are lower grade and shorter staple cottons, earlier studies showed that the relation between prices received by growers in local markets and grade and staple length was

[1] Credit is due Arthur W. Palmer for general supervision and helpful suggestions; B. Youngblood for his contributions to the study in its beginning; the grade and staple statistics project for classification of the samples and for cooperation in the collection and tabulation of the data; and ginners, warehousemen, and local buyers for making data available.

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extremely irregular. In many cases prices for higher grades and longer staples were lower than prices for lower grades and shorter staples.[2]

Prices received by growers on the basis of grade and staple length are important considerations in determining to what extent they can afford to improve the quality of cotton produced. A practical program for improving or maintaining the quality of cotton in the various localities should take into account the influence of prices received by growers on the quality of cotton produced. Where the prices received by growers are the same for all qualities of cotton, the growers are naturally more interested in yields than in quality, since under these conditions profits vary directly with yields. Growers are unlikely to change to or to continue to grow the longer staple varieties unless differences in income resulting from prices received, along with the yields, are adequate to convince them that longer staple varieties are at least as profitable as the shorter staple varieties.

These facts may well be remembered in connection with statistically unverifiable statements (*17*),[3] indicating deterioration in the quality of the cotton produced in various sections of the United States since the advent of the bollweevil in 1892. It is known that since 1929–30 the proportion of the United States crop having staples shorter than seven-eighths inch has decreased and the proportion with staples fifteen-sixteenths inch and longer has increased. The average staple length has increased from 15.11 sixteenths of an inch for the crop of 1929 to 15.45 sixteenths of an inch for the crop of 1932 (*26*). The alleged deterioration during earlier years has been attributed to the fact that prices received by growers were not such as to induce them to grow longer staple varieties; to the invasion of the bollweevil, which stimulated the development and use of early maturing varieties of shorter staple cotton; to the expansion of cotton acreage in areas less favorable to the production of longer staple varieties; to the mixing of varieties at the gins and in the fields; to deterioration in soil fertility; and to other factors. This study deals with the first of these factors, namely, the prices received by growers.

PREVIOUS INVESTIGATIONS OF THE RELATION BETWEEN PRICES AND GRADE AND STAPLE LENGTH

Several investigations of variations in prices received by growers, as related to grade and staple length of cotton sold, were made prior to 1928. The earliest of these studies reported was that made in Oklahoma (*36*) in 1912. During the season of 1913–14 the study was expanded to cover the entire Cotton Belt (*38*). Similar studies were made in North Carolina (*27*) during the seasons 1914–15 and 1915–16 and in Arkansas (*3*) during the seasons 1913–14, 1914–15, and 1915–16. These studies showed that, although the prices received by growers in the same local market on the same date often varied considerably, they did not always vary directly with the grade and staple length of the cotton. Studies made in four local markets in Texas (*14*) in 1926 showed that prices received by growers in the same local markets on the same date did not generally vary appreciably with the grade and staple length of the cotton sold, but

[2] HOWELL, L. D., and BURGESS, J. S., JR. FARM PRICES OF COTTON IN RELATION TO ITS GRADE AND STAPLE LENGTH IN LOCAL MARKETS IN THE UNITED STATES, SEASONS 1928–29, 1929–30, AND 1930–31. U. S. Dept. Agr. [Prelim. Rept.], 71 pp., illus. 1932. [Mimeographed.]

[3] Italic numbers in parentheses refer to literature cited, p. 47.

that average prices received by growers in different local markets on the same date did vary directly with the average grade and staple length of the cotton sold. Similar data were collected in Alabama (*32*) in 1926 and 1927 and in South Carolina (*24*) in 1925, 1926, and 1927. Their results are similar for the most part to those reported in Texas.

Beginning in the 1928–29 season, data on prices received by growers for cotton of various grades and staple lengths were gathered in selected local markets throughout the Cotton Belt by the United States Department of Agriculture in cooperation with State agricultural experiment stations. Reports have been issued showing in more or less complete form the results of the analysis of data collected in Alabama (*32*), Arkansas (*29*), Georgia (*21, 22*), Louisiana (*16*), Mississippi (*23*), North Carolina (*25*), Oklahoma (*15*), South Carolina (*10, 19, 24*), and Tennessee (*1*).

LOCAL MARKETS DEFINED AND DESCRIBED (*12*)

Farmers' local cotton markets constitute that part of the cotton-marketing system at which farmers and buyers come in direct contact for the purpose of selling and buying cotton. The farmers' local market represents the first step in the movement of cotton from the hands of the growers to the ultimate consumers. The market places, which in this bulletin are referred to as local markets, are to be found in almost every village, town, and city in the cotton-producing area of the United States. The volume of sales in these local markets varies from a few hundred bales at crossroad stores and country gins to many thousands of bales in the larger cities. The greater part of the crop is sold in the smaller cities and towns.

These local markets supply a meeting place for growers and buyers and give farmers an opportunity to bargain individually in the sale of their cotton; they furnish a ready and convenient market where farmers may sell their cotton at almost any time; they serve as a point for assembling cotton in such quantities as to facilitate handling; and they serve as a medium through which the demand for cotton is transmitted to growers.

The trading personnel of the local markets consists of cotton growers and local buyers. Farmers, as a rule, know very little about the classification of cotton. Their bargaining power is determined largely by their business judgment and their indebtedness to buyers. The number of local buyers varies from only 1 in some markets to more than 20 in others. Among them may be representatives of large cotton firms or mills who buy for their firms on joint account, on salary, or on commission; supply merchants, fertilizer dealers, gin operators, and others who take cotton on account of debts of farmers or for increasing their volume of business; and local cotton merchants who are interested primarily in buying and selling cotton.

The facilities available and the methods of handling cotton in local markets vary considerably. In some of these markets there is a public square, a cotton yard, or a railroad platform where buyers and farmers meet and where the cotton is sold. In other markets farmers deliver their cotton directly from the gin to a warehouse where the bales are weighed and sampled and receipts are issued

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in the farmer's name. With the samples and receipts obtained at the warehouse the farmers bargain with local buyers for the sale of their cotton.

In some local markets the local buyers obtain information on futures prices every 15 minutes and on spot prices at the close of the market through the commercial news department of telegraph companies. This and other information is used in determining the maximum prices local buyers can afford to pay growers for cotton. Many local buyers receive limits from merchants in central markets as a basis for buying. In making these limits the merchants take into account the quality of cotton recently received from the local market along with other considerations.

QUALITY OF COTTON

The term "quality" as applied to cotton refers to all the physical properties of cotton that affect its usefulness. These properties are described for commercial purposes in terms of grade, staple length, and character (*30*). Grade is a term denoting a composite of (1) color, luster, and brightness of the lint; (2) nature and quantity of foreign matter present, such as leaf, shale, motes, sand, and dust; and (3) preparation resulting from ginning as indicated by smoothness of fiber, "neppiness", nappiness, and whether or not the fibers are gin cut or stringy. Staple length of cotton means the normal length by measurement of a typical portion of its fibers and is determined commercially by a certain pulling of the staple with the hands (*39*). As every sample contains fibers of varying lengths, the drawing out of representative fibers is a process involving much skill. Character of cotton includes all elements of cotton quality not included in grade or staple length.

In determining the spinning quality of the fibers the character of cotton is important, but the factors affecting it are not very definitely known. Differences in character are recognized in the markets, and the prices paid doubtless reflect these to some extent; but in the absence of standards for character no attempt has been made in this study to relate the prices received by growers to the character of the cotton.

The proportional distributions by grades and staple lengths of cotton included in the sample of individual bale sales of Extra White, White, and Spotted cotton ginned in the United States are shown in tables 1 and 2. Although the proportional distribution by grade and staple length of cotton included in the price study was on the whole not very different from that for all upland cotton ginned in the United States, it will be noted that the proportions of the longer staples included in the price study were somewhat smaller than those for cotton ginned in the United States. The smaller proportion of the longer staples included in this study than were found for the domestic crops taken as a whole are largely accounted for by the fact that irrigated cotton was not included in this study and that only a small sample of individual bale sales was obtained in the Mississippi Delta because most of the cotton in the Delta was sold in round lots.

TABLE 1.—*Percentage distribution by grade of Extra White, White, and Spotted cotton included in the price study in selected local markets and ginned in the United States,*[1] *seasons 1928–29 to 1932–33*

Grade	1928–29		1929–30		1930–31		1931–32		1932–33	
	Local market sample	Ginnings in the United States	Local market sample	Ginnings in the United States	Local market sample	Ginnings in the United States	Local market sample	Ginnings in the United States	Local market sample	Ginnings in the United States
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
White:[2]										
1, Middling Fair	(3)	(3)								
2, Strict Good Middling	0.1	0.3	0.1	0.3	0.1	0.1	(3)	0.1	(3)	(3)
3, Good Middling	9.4	12.7	6.2	7.3	8.1	7.4	5.6	6.2	2.9	2.8
4, Strict Middling	33.9	35.6	30.0	28.3	34.0	33.5	38.4	36.6	29.9	26.0
5, Middling	24.8	23.8	31.3	31.4	32.8	31.6	31.9	32.2	35.4	36.2
6, Strict Low Middling	10.0	10.0	12.7	13.4	13.3	12.0	11.6	11.0	10.3	13.3
7, Low Middling	2.9	3.2	4.9	5.7	4.1	4.3	3.6	4.0	1.8	2.8
8, Strict Good Ordinary	1.1	1.8	1.8	2.0	.6	1.0	1.9	2.6	.3	.9
9, Good Ordinary	.4	.6	.5	.6	.1	.2	1.2	1.0	.1	.4
Total	82.6	88.0	87.5	89.0	93.1	91.1	94.2	93.7	80.7	82.4
Spotted:										
3, Good Middling	2.5	1.0	.5	.3	.9	1.1	.9	.7	1.9	1.5
4, Strict Middling	8.7	5.7	5.5	4.5	3.4	4.1	2.9	2.6	10.1	8.4
5, Middling	4.2	3.3	4.6	4.0	1.7	2.5	1.4	1.5	5.6	5.4
6, Strict Low Middling	1.7	1.4	1.5	1.7	.8	1.0	.5	1.1	1.3	1.7
7, Low Middling	.3	.6	.4	.5	.1	.2	.1	.4	.4	.6
Total	17.4	12.0	12.5	11.0	6.9	8.9	5.8	6.3	19.3	17.6
Grand total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

[1] U. S. Dept. Agr. Statis. Bull. 47 (*26*).
[2] Extra White cotton included.
[3] Less than 0.05 percent.

TABLE 2.—*Percentage distribution by staple length of Extra White, White, and Spotted cotton included in the price study in selected local markets and ginned in the United States,*[1] *seasons of 1928–29 to 1932–33*

Staple length (inches)	1928–29		1929–30		1930–31		1931–32		1932–33	
	Local market sample	Ginnings in the United States	Local market sample	Ginnings in the United States	Local market sample	Ginnings in the United States	Local market sample	Ginnings in the United States	Local market sample	Ginnings in the United States
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
Shorter than 7/8	12.3	13.5	20.3	19.8	8.4	13.3	4.7	6.0	4.0	6.5
7/8 and 29/32	43.3	41.9	44.0	38.0	37.8	38.7	30.9	39.7	39.2	37.7
15/16 and 31/32	25.7	22.9	21.3	19.1	31.8	25.0	35.0	27.2	34.6	28.9
1 and 1 1/32	11.8	11.2	9.8	11.8	16.0	12.6	22.0	15.4	18.0	14.4
1 1/16 and 1 3/32	4.0	5.6	3.3	6.6	4.9	7.1	6.5	6.5	3.8	6.9
1 1/8 and 1 5/32	2.2	3.5	1.2	3.9	1.0	2.9	.8	3.6	.4	4.9
1 3/16 and 1 7/32	.6	1.2	.1	.8	.1	.4	.1	1.4	(2)	.7
1 1/4 and longer	.1	.2	(2)	(2)	(2)	(2)	-------	.2	-------	(2)
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

[1] U. S. Dept. Agr. Statis. Bull. 47 (*26*).
[2] Less than 0.05 percent.

All staple lengths of cotton grown in the United States compete directly with cotton grown in other countries. Cotton 7/8 inch and shorter in staple competes directly with cotton grown in India, China, and other foreign countries. Cotton 15/16 inch to 1 1/32 inches in staple competes directly with cotton grown chiefly in Russia, Brazil, and Argentina. Cotton 1 1/16 inches and longer in staple

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competes directly with cotton grown chiefly in Egypt, Peru, Uganda, Sudan, and Brazil. In order that farmers may make such adjustments as may be necessary to meet this competition to the best advantage, it is necessary that information be had not only on differences in yields and in other factors affecting cost of production but also on differences in prices received for cotton of the various grades and staple lengths.

OBJECTIVES OF THIS STUDY

The objectives of this study were (1) to determine the extent to which prices received by growers in selected local markets for individual bales varied on the basis of their grade and staple length, (2) to compare premiums for the higher grades and longer staples and discounts for the lower grades and shorter staples in local markets with those quoted in central markets, and (3) to determine to what extent average prices in the different local markets varied with the average quality of the cotton sold as indicated by grade and staple length.

As a basis for this study, the price data mentioned above, collected in the various States in the period 1928–29 to 1932–33 have been analyzed from a national point of view.

This bulletin also calls attention to some of the factors responsible for or associated with these variations, indicates some of the influences of the variations in prices received by growers for different grades and staple lengths on the quality of the cotton grown, and suggests means of bringing about a better adjustment of the quality of cotton produced to mill requirements.

METHOD OF PROCEDURE AND SCOPE OF THIS STUDY

LOCAL MARKET PRICES

Data were collected in 141 local markets [4] in 1928–29, 115 in 1929–30, 114 in 1930–31, 38 in 1931–32, and 53 in 1932–33. These markets are widely distributed over the Cotton Belt and were selected to represent the various types of local markets. Their location is shown in figure 1. Arrangements were made by the United States Department of Agriculture, in cooperation with State agricultural experiment stations, to secure from a ginner at each of these markets a sample from each bale of cotton ginned at his plant during the season. These samples were mailed to the offices of the United States Department of Agriculture at Atlanta, Ga.; Memphis, Tenn.; and Dallas or Austin, Tex., where they were classed [5] according to the official cotton standards of the United States, by specialists in cotton classing regularly employed by the United States Department of Agriculture.

Data on prices received by growers and on date of sale were obtained from local buyers and were recorded along with the Government classification, and the type of buyer (ginner, storekeeper, etc.) who bought each bale. Information on marketing methods and prac-

[4] These local markets were selected at points where arrangements had already been made for obtaining samples for grade and staple statistics. A reduction in the funds available for the collection of price data accounts for the smaller number of markets included in the study in 1931–32 and in 1932–33 than in previous seasons.

[5] The classifications were based on samples taken from the press box at the gin, although most of the cotton was sold on the basis of samples cut from the bales.

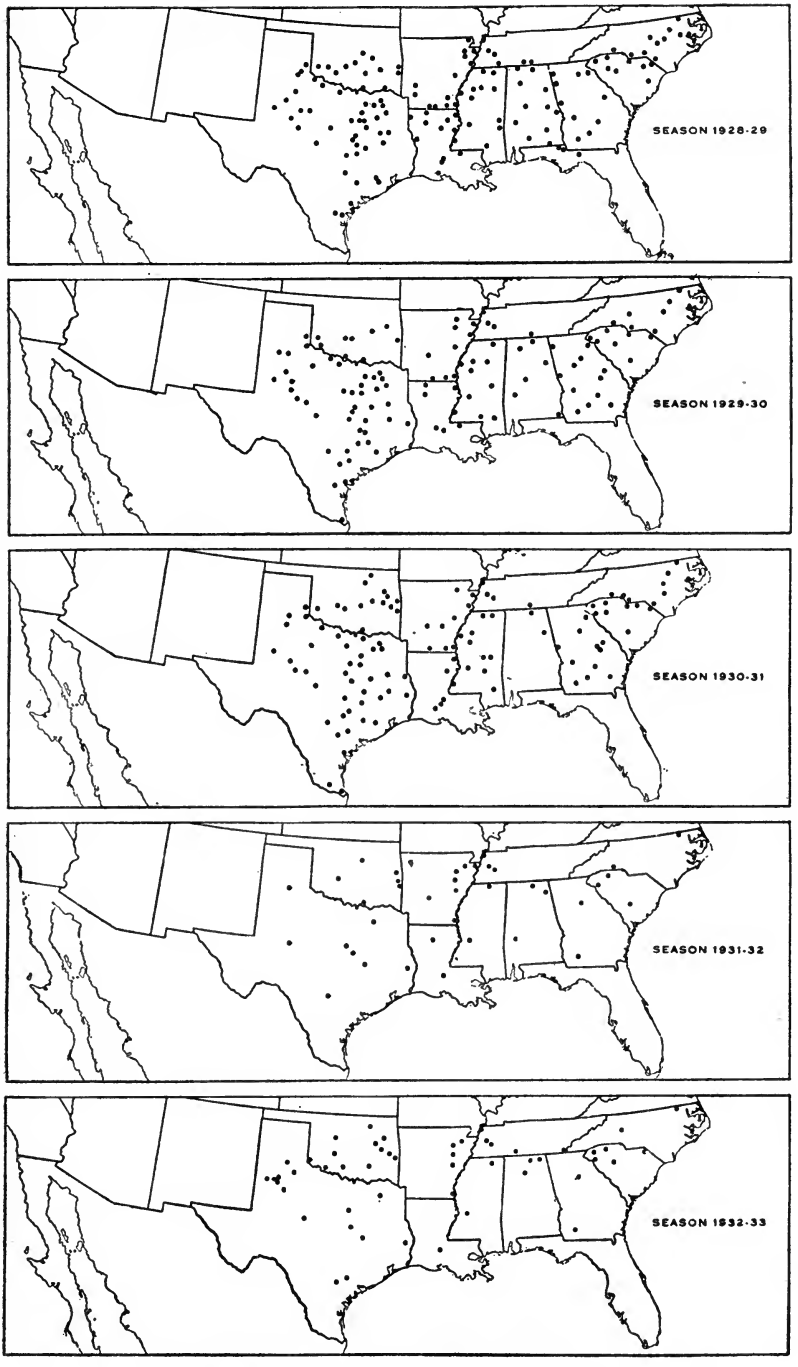

FIGURE 1.—LOCATION OF FARMERS' LOCAL MARKETS STUDIED.

Local markets included in the study of farm prices of cotton as related to its grade and staple length are widely distributed over the Cotton Belt and were selected to represent the various types of local markets.

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tices and on central markets and mill towns, if any, to which cotton was shipped, together with data on handling and storage charges, insurance, and freight rates were obtained for each market for use in interpreting the price data. Complete data were obtained for 106,603 individual-bale sales in 1928–29, 99,493 in 1929–30, 80,725 in 1930–31, 28,836 in 1931–32, and 30,762 in 1932–33. Before making the analysis, data on cotton sold by farmers in round lots were separated from data on cotton sold as individual bales. (The details of the methods of analyzing these data are given in the appendix, p. 49.)

CENTRAL MARKET PRICES

The central-market prices used include average prices quoted for Middling ⅞-inch White cotton at the 10 designated spot markets (Augusta, Dallas, Galveston, Houston, Little Rock, Memphis, Montgomery, New Orleans, Norfolk, and Savannah); average premiums and discounts for grade at the 10 designated spot markets; average premiums for staples 15/16 inch and 1 inch at the 6 spot markets (Dallas, Galveston, Houston, Little Rock, Memphis, and New Orleans); average premiums for staples 1 1/16 inches and longer at Memphis and New Orleans; and average discounts for 13/16-inch staples at Houston, Galveston, and New Orleans. Averages were obtained by weighing these central-market quotations by the number of bales of cotton of the same description sold on the same day and included in the data on prices received by growers in local markets. This weighting eliminates the influence of differences in date of sale on differences between local-market and central-market prices.

Central-market quotations are here used as a basis for comparison, not because they are considered entirely satisfactory measures of the differences in value, for spinning purposes, of cotton of the various grades and staple lengths, but because no better measures were found. Prices that mills are economically justified in paying for cotton of different grades and staples are limited by its value for spinning purposes. Prices quoted in central markets are thought to reflect, fairly accurately, mill premiums and discounts for grades and staple lengths. Central-market quotations are used instead of mill quotations because daily quotations for mill markets showing premiums and discounts for all grades and staples included in this study are not available. Differences in spinning value of cotton of the various grades and staple lengths change from time to time as a result of differences in the supply-and-demand situation. Competition in mill markets may be limited to such an extent that prices paid by mill buyers do not reflect accurately the differences in spinning value of cotton of the various grades and staple lengths and prices in central markets may represent a somewhat further deflection from a true representation of these differences in spinning value. But, despite these imperfections, it is believed that central-market quotations reflect differences in the spinning value of the various grades and staples accurately enough for their use in this connection to give significant results.

The use of central-market premiums and discounts for grade and staple length as a basis for comparison does not necessarily mean that prices to growers in local markets should reflect premiums and discounts equal to those quoted in central markets for large lots of even-running cotton. It is not known to what extent premiums and discounts for grade and staple length for cotton sold in even-running lots

differ from those for cotton bought on "basis Middling" contract, but limits used by merchants in New Orleans for purchases made in the interior were found not to be materially out of line with the official quotations for the medium grades and staples.

RELATION BETWEEN PRICES AND THE GRADE AND STAPLE LENGTH OF INDIVIDUAL BALES

PRICES OF SPECIFIED GRADES AND STAPLES IN LOCAL MARKETS ON SELECTED DAYS

The prices received by growers for cotton of the same grade and staple length sold in the same local market on the same day varied widely. Furthermore, prices received for cotton of different grades and staple lengths varied so irregularly that it was not unusual for some farmers to receive considerably higher prices for cotton of some grades and staples than other farmers received for cotton of higher grade and longer staple sold in the same local market on the same day.

Irregularities in the relationship between prices and grade and staple length are shown in tables 3, 17, 18, and 19. In market A, for example, on October 10, 1928, the prices received by growers for Strict Middling 1⅛-inch cotton varied from 16 cents a pound to 21 cents a pound. On the same day in the same local market the highest price paid for Strict Middling $^{15}/_{16}$-inch cotton was 20 cents a pound, whereas the lowest price paid for Middling 1⅛-inch cotton was 18.75 cents a pound. That only a small part of these irregular variations is accounted for by fluctuations in prices during the day is indicated by the fact that on October 10, 1928, the prices of New York futures contracts for December delivery varied only 10 points.[6] Data showing more or less similar variations in other markets and in other years are also shown in tables 3, 17, 18, and 19.

[6] A "point" is one one-hundredth of 1 cent.

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TABLE 3.—*Price per pound received by growers for White cotton of various grades and staple lengths sold in selected local markets on specified dates, season 1928–29* [1]

MARKET A, 20 BUYERS OF DIFFERENT TYPES, OCT. 10, 1928 [2]

Grade	⅞ inch		15/16 inch		1 inch		1 1/16 inches		1 1/8 inches		1 3/16 inches		1 1/4 inches and longer	
	Sales	Price	Sales	Price	Sales	Price	Sales	Price	Sales	Price	Sales	Price	Sales	Price
	Bales	*Cents*	*Bales*	*Cents*	*Bales*	*Cents*	*Bales*	*Cents*	*Bales*	*Cents*	*Bales*	*Cents*	*Bales*	*Cents*
3, Good Middling							1	20.00	3	21.00	1	20.50	1	20.00
							1	21.00			1	20.75	1	21.50
											1	21.00		
											1	21.13		
4, Strict Middling	1	21.00	1	18.63	1	19.38	1	19.00	1	16.00	2	21.00	1	20.00
			2	20.00			2	19.50	1	18.75	2	21.13	1	20.75
							5	20.00	2	19.25	2	22.00		
									1	19.38				
									1	19.50				
									1	19.75				
									3	20.00				
									2	21.00				
5, Middling					2	19.00	2	19.00	2	18.75	2	20.00	1	21.00
							1	19.13	3	19.00	1	21.00		
							2	19.25	1	19.50	1	22.00		
							1	19.50	2	19.75				
							1	20.00	2	20.00				
									2	20.25				
									1	21.00				
6, Strict Low Middling					1	16.75			1	19.63				
7, Low Middling					1	16.75			1	21.00				

MARKET B, 1 BUYER, WHO BUYS ON COMMISSION FOR A LOCAL MILL, OCT. 6, 1928 [3]

3, Good Middling			1	18.00	1	18.13								
			6	18.13										
4, Strict Middling	1	18.00	4	18.00	1	18.13	1	18.00						
	2	18.13	5	18.13										
5, Middling	2	18.00	2	18.13										
	1	18.13												
6, Strict, Low Middling			1	18.13										
7, Low Middling	1	18.13												

[1] No round-lot sales are included.
[2] The price of New York futures contracts for December delivery varied 10 points on this date.
[3] The price of New York futures contracts for December delivery varied 18 points on this date.

These wide and irregular variations, which are considered fairly typical of local-market prices, show that the influence of quality, as indicated by grade and staple-length designations of Government classers on prices received by growers, at least so far as individual bales are concerned, is frequently more than counterbalanced by other factors. Lack of knowledge of the correct classification and commercial value of the cotton on the part of farmers and of many local buyers, differences in bargaining power of farmers and of local buyers, and fluctuations in prices during the day, are considered the most important factors responsible for these irregular variations in prices on the basis of grade and staple length.

PREMIUMS AND DISCOUNTS FOR GRADE

Average prices received by growers for the higher grades were generally somewhat higher than those received for cotton of lower grade but of the same staple length sold in the same local market on the same day. It was found, however, that premiums for the higher grades and also discounts for the lower grades averaged considerably less in local markets than did those quoted in central markets (table 4 and fig. 2).

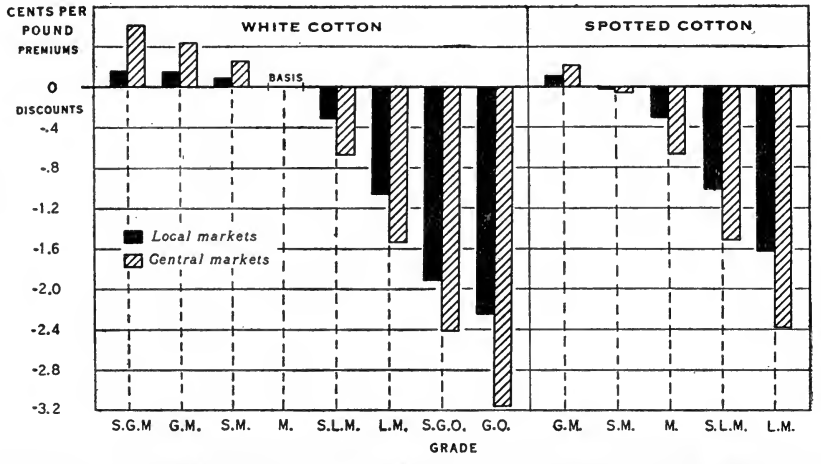

FIGURE 2.—AVERAGE PREMIUMS AND DISCOUNTS FOR SPECIFIED GRADES OF 7/8-INCH COTTON IN SELECTED LOCAL MARKETS AND IN CENTRAL MARKETS, SEASONS 1928–29 TO 1932–33.

Premiums received by growers for grades above Middling averaged only one-third of those quoted in central markets. Discounts made to growers for grades below Middling averaged about 60 percent of those quoted in central markets.

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TABLE 4.—*Average premiums and discounts [1] for specified grades of 7/8-inch cotton in selected local markets and in central markets,[2] seasons 1928–29 to 1932–33*

Grade	Local markets: Size of sample	Local markets: Premiums and discounts (−)	Central markets: Premiums and discounts (−)
	Bales	*Cents*	*Cents*
SEASON 1928–29			
White: [3]			
2, Strict Good Middling	46	0.14	0.60
3, Good Middling	3,180	.21	.40
4, Strict Middling	14,498	.12	.26
5, Middling (basis)	11,377	.00	.00
6, Strict Low Middling	4,395	−.34	−.77
7, Low Middling	1,319	−.94	−1.57
8, Strict Good Ordinary	425	−1.68	−2.40
9, Good Ordinary	168	−2.66	−3.26
Spotted:			
3, Good Middling	1,153	.13	.23
4, Strict Middling	4,936	−.01	−.03
5, Middling	2,234	−.29	−.75
6, Strict Low Middling	535	−.97	−1.53
7, Low Middling	81	−1.38	−2.31
SEASON 1929–30			
White: [3]			
2, Strict Good Middling	22	0.21	0.58
3, Good Middling	1,782	.14	.43
4, Strict Middling	12,277	.11	.27
5, Middling (basis)	14,264	.00	.00
6, Strict Low Middling	5,849	−.40	−.76
7, Low Middling	2,155	−1.46	−1.68
8, Strict Good Ordinary	614	−2.54	−2.76
9, Good Ordinary	132	−2.48	−3.75
Spotted:			
3, Good Middling	192	.08	.19
4, Strict Middling	2,635	−.01	−.07
5, Middling	1,984	−.34	−.74
6, Strict Low Middling	555	−1.16	−1.64
7, Low Middling	101	−2.02	−2.70
SEASON 1930–31			
White: [3]			
2, Strict Good Middling	32	0.17	0.70
3, Good Middling	1,761	.07	.52
4, Strict Middling	8,778	.05	.31
5, Middling (basis)	10,214	.00	.00
6, Strict Low Middling	4,766	−.32	−.69
7, Low Middling	1,552	−.96	−1.60
8, Strict Good Ordinary	230	−1.61	−2.57
9, Good Ordinary	27	−1.77	−3.59
Spotted:			
3, Good Middling	274	−.02	.21
4, Strict Middling	1,270	−.11	−.04
5, Middling	673	−.38	−.67
6, Strict Low Middling	310	−1.01	−1.55
7, Low Middling	36	−1.55	−2.48
SEASON 1931–32			
White: [3]			
3, Good Middling	500	0.10	0.44
4, Strict Middling	3,170	.03	.26
5, Middling (basis)	2,913	.00	.00
6, Strict Low Middling	1,068	−.06	−.36
7, Low Middling	227	−.15	−.75
8, Strict Good Ordinary	111	−.52	−1.07
9, Good Ordinary	48	−.92	−1.34
Spotted:			
3, Good Middling	100	.00	.21
4, Strict Middling	298	−.05	.00
5, Middling	125	−.11	−.36
6, Strict Low Middling	22	−.45	−.77
7, Low Middling	7	−.68	−.99

See footnotes at end of table.

TABLE 4.—*Average premiums and discounts [1] for specified grades of 7/8-inch cotton in selected local markets and in central markets,[2] seasons 1928–29 to 1932–33*—Continued

SEASON 1932-33

Grade	Local markets		Central markets
	Size of sample	Premiums and discounts (−)	Premiums and discounts (−)
	Bales	*Cents*	*Cents*
White: [3]			
3, Good Middling	248	0.13	0.34
4, Strict Middling	2,961	.01	.24
5, Middling (basis)	4,336	.00	.00
6, Strict Low Middling	1,406	−.07	−.29
7, Low Middling	247	−.16	−.59
8, Strict Good Ordinary	46	−.47	−.87
9, Good Ordinary	10	−.62	−1.24
Spotted:			
3, Good Middling	168	.04	.23
4, Strict Middling	1,241	−.04	.00
5, Middling	742	−.16	−.28
6, Strict Low Middling	60	−.40	−.57
7, Low Middling	12	−.57	−.91
TOTAL			
White: [3]			
2, Strict Good Middling	100	0.16	0.63
3, Good Middling	7,471	.15	.44
4, Strict Middling	41,684	.09	.27
5, Middling (basis)	43,104	.00	.00
6, Strict Low Middling	17,484	−.32	−.68
7, Low Middling	5,500	−1.08	−1.54
8, Strict Good Ordinary	1,426	−1.91	−2.43
9, Good Ordinary	385	−2.27	−3.16
Spotted:			
3, Good Middling	1,887	.09	.22
4, Strict Middling	10,380	−.03	−.04
5, Middling	5,758	−.30	−.67
6, Strict Low Middling	1,482	−1.02	−1.53
7, Low Middling	237	−1.62	−2.39

[1] Premiums and discounts in cents per pound from the price of Middling 7/8-inch White cotton. The price of Middling 7/8-inch White cotton in the selected local markets averaged 17.86 cents per pound in 1928–29, 17.20 cents per pound in 1929–30, 9.74 cents per pound in 1930–31, 5.75 cents per pound in 1931–32, 6.21 cents per pound in 1932–33, and 13.73 cents per pound for the 5 seasons combined. Central-market quotations averaged 18.36, 17.58, 10.03, 5.84, 6.30, and 14.07 cents per pound, respectively. Data for these averages are confined largely to sales made during the first 8 or 9 months of the season.

[2] Average quoted prices for Middling 7/8-inch cotton and average premiums and discounts for grade at the 10 designated spot markets were weighted by the number of bales of cotton of the same grade and staple length designation sold on the same day and included in the sample of cotton shown for local markets.

[3] Extra White cotton included. Central-market quotations for Extra White cotton are the same as for the corresponding grades of White cotton.

For example, data for all markets for the five seasons combined show that premiums for the grades of 7/8-inch White cotton higher than Middling averaged 0.09 cent a pound for Strict Middling, 0.15 cent a pound for Good Middling, and 0.16 cent a pound for Strict Good Middling in local markets; whereas central-market premiums averaged 0.27 cent a pound for Strict Middling, 0.44 cent a pound for Good Middling, and 0.63 cent a pound for Strict Good Middling. Discounts for the lower grades in local markets averaged 0.32 cent a pound for Strict Low Middling, 1.08 cents a pound for Low Middling, 1.91 cents a pound for Strict Good Ordinary, and 2.27 cents a pound for Good Ordinary; whereas central-market discounts averaged 0.68 cent a pound for Strict Low Middling, 1.54 cents a pound for Low Middling, 2.43 cents a pound for Strict Good Ordinary, and 3.16 cents a pound for Good Ordinary.

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Average premiums for the higher grades and average discounts for the lower grades in the selected local markets for cotton of various staple lengths were somewhat less than those for cotton of ⅞-inch staple (table 5). The influence of staple length was largely eliminated in the average premiums and discounts for grade for various staple lengths by comparing prices of cotton of different grades but of the same staple length and by averaging the premiums and discounts for grade for the longer staple cottons with those for the shorter staple cottons.

TABLE 5.—*Average premiums and discounts* [1] *for specified grades of cotton of various staple lengths* [2] *in selected local markets, seasons 1928–29 to 1932–33*

SEASON 1928–29

Grade	Size of sample	Premiums and discounts (−)	Grade	Size of sample	Premiums and discounts (−)
White: [3]	*Bales*	*Cents*	Spotted:	*Bales*	*Cents*
2, Strict Good Middling	100	0.10	3, Good Middling	2,319	0.12
3, Good Middling	7,780	.19	4, Strict Middling	8,778	.00
4, Strict Middling	33,984	.13	5, Middling	4,258	−.30
5, Middling (basis)	26,426	.00	6, Strict Low Middling	1,380	−1.06
6, Strict Low Middling	10,226	−.31	7, Low Middling	232	−1.47
7, Low Middling	2,731	−.88			
8, Strict Good Ordinary	993	−1.58			
9, Good Ordinary	316	−2.43			

SEASON 1929–30

White: [3]			Spotted:		
2, Strict Good Middling	76	0.02	3, Good Middling	458	0.24
3, Good Middling	5,327	.07	4, Strict Middling	5,351	.10
4, Strict Middling	28,927	.09	5, Middling	4,372	−.15
5, Middling (basis)	31,117	.00	6, Strict Low Middling	1,312	−.69
6, Strict Low Middling	12,296	−.38	7, Low Middling	279	−1.48
7, Low Middling	4,315	−1.29			
8, Strict Good Ordinary	1,203	−2.17			
9, Good Ordinary	274	−2.40			

SEASON 1930–31

White: [3]			Spotted:		
2, Strict Good Middling	111	0.19	3, Good Middling	668	0.12
3, Good Middling	5,706	.03	4, Strict Middling	2,694	.41
4, Strict Middling	26,378	.05	5, Middling	1,324	−.31
5, Middling (basis)	26,483	.00	6, Strict Low Middling	526	−.95
6, Strict Low Middling	10,489	−.30	7, Low Middling	67	−1.20
7, Low Middling	3,073	−.89			
8, Strict Good Ordinary	452	−1.54			
9, Good Ordinary	52	−1.89			

SEASON 1931–32

White: [3]			Spotted:		
2, Strict Good Middling	9	0.18	3, Good Middling	231	0.07
3, Good Middling	1,399	.08	4, Strict Middling	812	.03
4, Strict Middling	10,685	.04	5, Middling	356	.01
5, Middling (basis)	9,201	.00	6, Strict Low Middling	106	−.27
6, Strict Low Middling	3,220	−.07	7, Low Middling	26	−.54
7, Low Middling	811	−.28			
8, Strict Good Ordinary	293	−.46			
9, Good Ordinary	63	−.76			

See footnotes at end of table.

TABLE 5.—*Average premiums and discounts* [1] *for specified grades of cotton of various staple lengths* [2] *in selected local markets, seasons 1928–29 to 1932–33*—Con.

SEASON 1932-33

Grade	Size of sample	Premiums and discounts (−)	Grade	Size of sample	Premiums and discounts (−)
White: [3]	*Bales*	*Cents*	Spotted:	*Bales*	*Cents*
2, Strict Good Middling	2	0.26	3, Good Middling	543	0.02
3, Good Middling	792	.04	4, Strict Middling	2,986	−.04
4, Strict Middling	8,963	.00	5, Middling	1,458	−.13
5, Middling (basis)	10,893	.00	6, Strict Low Middling	119	−.30
6, Strict Low Middling	2,992	−.07	7, Low Middling	18	−.49
7, Low Middling	450	−.16			
8, Strict Good Ordinary	59	−.48			
9, Good Ordinary	10	−.62			

TOTAL

White: [3]			Spotted:		
2, Strict Good Middling	298	0.12	3, Good Middling	4,219	0.12
3, Good Middling	21,004	.10	4, Strict Middling	20,621	.07
4, Strict Middling	108,937	.08	5, Middling	11,768	−.22
5, Middling (basis)	104,120	.00	6, Strict Low Middling	3,443	−.85
6, Strict Low Middling	39,223	−.29	7, Low Middling	622	−1.38
7, Low Middling	11,380	−.97			
8, Strict Good Ordinary	3,000	−1.68			
9, Good Ordinary	715	−2.21			

[1] Premiums and discounts in cents per pound from the price of Middling White cotton of the same staple length. The price of Middling White cotton of various staple lengths in the selected local markets averaged 18.03 cents per pound in 1928–29, 17.23 cents per pound in 1929–30, 9.93 cents per pound in 1930–31, 5.88 cents per pound in 1931–32, 6.53 cents per pound in 1932–33, and 13.45 cents per pound for the 5 seasons combined. Data for these averages are confined largely to sales made during the first 8 or 9 months of the season.

[2] The influence of staple length was largely eliminated by comparing prices of cotton of different grades but of the same staple length.

[3] Extra White cotton included.

Average premiums and discounts for grade in local markets and in central markets varied somewhat irregularly from year to year; but, on the whole, these average premiums and discounts when expressed in cents a pound decreased from 1928–29 to 1932–33 along with the marked decline in cotton prices. When expressed as percentages of the Middling ⅞-inch prices, however, premiums and discounts for grade in local markets varied irregularly from year to year with no definite trends, whereas in central markets premiums and discounts were relatively greater in 1930–31 and in 1931–32 than in the other years included in this study. That the irregular variations in premiums and discounts for grade in local markets from year to year are not accounted for by the failure to include the same local markets in the study each year is indicated by the fact that average premiums and discounts for grade in 13 selected markets included each year since 1928–29 show irregularities somewhat similar to those shown for all markets combined.

Average premiums and discounts for grade made to growers varied considerably from market to market. Differences between average premiums and discounts in individual local markets of the same type in many cases were as great as, or greater than, the differences between average premiums and discounts in local markets of different types. Furthermore, prices paid by buyers of different types reveal no consistent relationships between type of buyer and the average premiums and discounts for grade made to growers. Average premiums and discounts for grade in the selected local markets show irregular

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variations from month to month. On the whole, however, some indications of increased premiums for the higher grades and increased discounts for the lower grades as the season advanced were in evidence during each of the years.

Two questions arise in connection with these averages, (1) To what extent are premiums and discounts quoted in central markets passed back to the grower at his local selling point, and (2) To what extent does the grower in making his individual sales actually realize the average premium or suffer the average penalty?

An answer to the first question is given by a comparison of the premiums and discounts for grade in local markets with those quoted in central markets. Premiums for White grades above Middling in local markets for the 5-year period amounted on an average to only 33 percent of those quoted in central markets and ranged from 25 percent for Strict Good Middling to 34 percent for Good Middling. Discounts for White grades below Middling in local markets amounted to 60 percent of those quoted in central markets and ranged from 47 percent for Strict Low Middling to 79 percent for Strict Good Ordinary. The proportion of central-market premiums for the higher grades reflected in local market prices was greater in 1928–29 than in any other year studied and decreased from 48 percent in 1928–29 to only 8 percent in 1932–33. The proportions of central-market discounts for the lower grades reflected in local-market prices varied somewhat irregularly from year to year but were considerably less in 1931–32 and 1932–33 than in any of the other years.

The extent to which premiums and discounts for grade made to individual farmers differed from the average premiums and discounts shown is indicated by the data presented in table 6. These data show that the average premiums and discounts for grade were not in close agreement with those of a large proportion of the individual sales. An examination of these data shows that the average premiums and discounts for grade (table 4), in many cases were less than the average variations in prices of individual bales of cotton of the same grade and staple length sold in the same local markets on the same days. Although the average prices received by growers for cotton above Middling in grade were somewhat higher than the average price received for Middling White cotton of the same staple length during the 5-year period, the prices received for 41 percent of the Strict Middling, 32 percent of the Strict Good Middling, and 38 percent of Good Middling were actually below the average price received for Middling White cotton of the same staple length. Despite the fact that the average prices received by growers for grades below Middling were lower than the average price received for Middling White cotton of the same staple length, the prices received for considerable proportions of the lower grade cotton were actually greater than the average price of Middling White cotton of the same staple length. The proportions of cotton of the lower grades for which growers received prices higher than the average price of Middling White cotton of the same staple length amounted to about 32 percent for Strict Low Middling, 14 percent for Low Middling, 7 percent for Strict Good Ordinary, and 6 percent for Good Ordinary White cotton. The distributions of variations in prices for each year were, in general, similar to those for the 5 years combined (table 20).

TABLE 6.—*Frequency distribution of variations in prices [1] per pound received by growers for individual bales of specified grades of White [2] cotton of ⅛-inch staple from the average price received for Middling White cotton of the same staple length in selected local markets, seasons 1928–29 to 1932–33 combined*

Variation (cents)	2, Strict Good Middling		3, Good Middling		4, Strict Middling		5, Middling		6, Strict Low Middling		7, Low Middling		8, Strict Good Ordinary		9, Good Ordinary	
	Bales	*Percent*	*Bales*	*Percent*	*Bales*	*Percent*	*Bales*	*Percent*	*Bales*	*Percent*	*Bales*	*Percent*	*Bales*	*Percent*	*Bales*	*Percent*
Under −6.00									2	(3)	4	0.1	7	0.5	1	0.3
−6.00 to −5.61											5	.1	9	.6	1	.3
−5.60 to −5.21									1	(3)	16	.3	37	2.6	10	2.6
−5.20 to −4.81							1	(3)	2	(3)	18	.3	24	1.7	8	2.1
−4.80 to −4.41							1	(3)	9	0.1	39	.7	32	2.2	12	3.1
−4.40 to −4.01					2	(3)	2	(3)	10	.1	38	.7	33	2.3	14	3.7
−4.00 to −3.61			1	(3)			2	(3)	17	.1	49	.9	39	2.7	32	8.3
−3.60 to −3.21					2	(3)	6	(3)	28	.2	111	2.0	60	4.2	32	8.3
−3.20 to −2.81					7	(3)	7	(3)	50	.3	159	2.9	109	7.7	46	11.9
−2.80 to −2.41					9	(3)	13	(3)	109	.6	237	4.3	127	8.9	39	10.1
−2.40 to −2.01			6	0.1	13	(3)	39	0.1	191	1.1	331	6.0	134	9.4	27	7.0
−2.00 to −1.61			6	.1	49	0.1	72	.2	366	2.1	503	9.2	156	11.0	19	4.9
−1.60 to −1.21			15	.2	131	.3	241	.6	705	4.0	599	10.9	152	10.7	24	6.2
−1.20 to −0.81			86	1.1	561	1.3	883	2.0	1,651	9.4	783	14.2	159	11.2	46	11.9
−0.80 to −0.41	2	2.0	523	7.0	2,941	7.1	3,915	9.1	3,214	18.4	949	17.3	146	10.2	23	6.0
−0.40 to −0.01	30	30.0	2,239	30.0	13,368	32.1	15,554	36.1	5,579	31.9	879	16.0	107	7.5	28	7.3
0.00 to 0.39	49	49.0	2,896	38.8	17,289	41.5	17,446	40.5	4,083	23.4	585	10.6	64	4.5	19	4.9
0.40 to 0.79	13	13.0	1,172	15.7	5,592	13.4	3,956	9.2	1,125	6.4	134	2.4	19	1.3	3	.8
0.80 to 1.19	4	4.0	274	3.7	1,218	2.9	744	1.7	241	1.4	37	.7	2	.1	1	.3
1.20 to 1.59	1	1.0	113	1.5	316	.8	160	.4	57	.3	12	.2	3	.2		
1.60 to 1.99	1	1.0	110	1.4	109	.3	34	.1	21	.1	7	.1	2	.1		
2.00 to 2.39			27	.4	57	.1	12	(3)	4	(3)	2	(3)	4	.3		
2.40 and over			3	(3)	20	.1	16	(3)	19	.1	3	.1	1	.1		
Total	100	100.0	7,471	100.0	41,684	100.0	43,104	100.0	17,484	100.0	5,500	100.0	1,426	100.0	385	100.0
	Cents		*Cents*		*Cents*		*Cents*		*Cents*		*Cents*		*Cents*		*Cents*	
Mean	0.16		0.15		0.09		0.00		−0.32		−1.08		−1.91		−2.27	
Standard error of mean	.04		.01		.00		.00		.00		.02		.04		.08	
Average deviation	.26		.35		.32		.32		.50		.88		1.18		1.28	
Approximate range [4]	2.40		7.20		8.40		8.40		11.20		10.40		10.40		7.60	

[1] Minus sign (−) means below the average price for Middling White cotton.
[2] Extra White cotton included.
[3] Less than 0.05 percent.
[4] The approximate range was measured from the midpoint of the extreme classes.

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PREMIUMS AND DISCOUNTS FOR STAPLE

Premiums for staples longer than ⅞ inch and discounts for staples shorter than ⅞ inch in selected local markets also averaged considerably less than those quoted in central markets [7] (table 7 and fig. 3).

Data for all markets for the five seasons combined show that for Middling White cotton premiums for staples longer than ⅞ inch averaged 0.04 cent a pound for 15/16 inch, 0.12 cent a pound for 1 inch, 0.29 cent a pound for 1 1/16 inches, 0.70 cent a pound for 1⅛ inches,

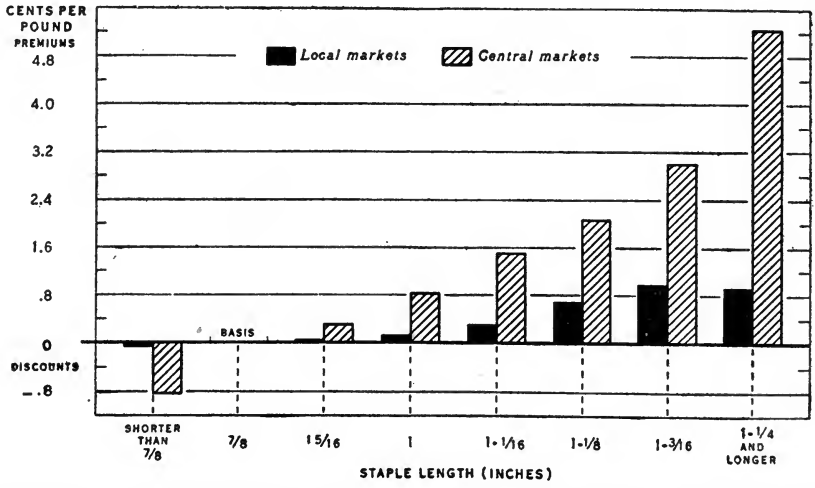

FIGURE 3.—AVERAGE PREMIUMS AND DISCOUNTS FOR SPECIFIED STAPLE LENGTHS OF MIDDLING WHITE COTTON IN SELECTED LOCAL MARKETS AND IN CENTRAL MARKETS, SEASONS 1928–29 TO 1932–33.

Discounts made to growers for cotton with staple lengths shorter than ⅞ inch averaged only 6 percent of those quoted in central markets for cotton 13/16 inch in staple. Premiums received by growers for staple lengths longer than ⅞ inch averaged only 17 percent of those quoted in central markets.

0.97 cent a pound for 1 3/16 inches, and 0.94 cent a pound for 1¼ inches and longer in local markets; whereas in central markets premiums averaged 0.33 cent a pound for 15/16 inch, 0.83 cent a pound for 1 inch, 1.51 cents a pound for 1 1/16 inches, 2.08 cents a pound for 1⅛ inches, 3.01 cents a pound for 1 3/16 inches, and 5.25 cents a pound for 1¼ inches and longer. During the same period average discounts for staples shorter than ⅞ inch amounted to only 0.05 cent a pound in local markets; whereas in central markets discounts for 13/16-inch cotton averaged 0.84 cent a pound.

[7] Bales sold in local markets, when classed in odd-numbered thirty-seconds of an inch have been tabulated as of the next lower sixteenth of an inch.

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TABLE 7.—*Average premiums and discounts* [1] *for specified staple lengths of Middling White* [2] *cotton in selected local markets and in central markets,* [3] *seasons 1928–29 to 1932–33*

SEASON 1928–29

Staple length (inches) [4]	Local markets: Size of sample	Local markets: Premiums and discounts (−)	Central markets: Premiums and discounts (−)	Staple length (inches) [4]	Local markets: Size of sample	Local markets: Premiums and discounts (−)	Central markets: Premiums and discounts (−)
	Bales	*Cents*	*Cents*		*Bales*	*Cents*	*Cents*
Shorter than 7/8	2,236	−0.08	[5] −0.54	1 1/16	1,221	0.45	1.65
7/8 (basis)	11,377	.00	.00	1 1/8	553	.98	2.08
15/16	6,813	.04	.28	1 3/16	171	1.13	2.95
1	3,318	.13	.82	1 1/4 and longer	47	.95	5.22
SEASON 1929–30							
Shorter than 7/8	5,658	−0.05	[5] −0.97	1 1/16	833	0.37	1.98
7/8 (basis)	14,264	.00	.00	1 1/8	262	.73	2.37
15/16	6,608	.07	.43	1 3/16	18	.82	3.25
1	2,711	.14	1.28	1 1/4 and longer	2	.68	5.94
SEASON 1930–31							
Shorter than 7/8	1,732	−0.04	[5] −1.00	1 1/16	1,233	0.18	1.55
7/8 (basis)	10,214	.00	.00	1 1/8	240	.23	2.00
15/16	8,097	.02	.38	1 3/16	23	.05	3.39
1	3,372	.11	.89				
SEASON 1931–32							
Shorter than 7/8	383	0.00	[5] −0.45	1 1/16	642	0.23	1.03
7/8 (basis)	2,913	.00	.00	1 1/8	77	.29	1.81
15/16	2,898	.03	.25	1 3/16	2	.33	2.93
1	2,139	.08	.56				
SEASON 1932–33							
Shorter than 7/8	315	−0.02	[5] −0.26	1 1/16	428	0.12	0.80
7/8 (basis)	4,336	.00	.00	1 1/8	37	.14	1.11
15/16	3,310	.04	.16	1 3/16	2	.14	2.00
1	1,809	.11	.41				
TOTAL							
Shorter than 7/8	10,324	−0.05	[5] −0.84	1 1/16	4,357	0.29	1.51
7/8 (basis)	43,104	.00	.00	1 1/8	1,169	.70	2.08
15/16	27,726	.04	.33	1 3/16	216	.97	3.01
1	13,349	.12	.83	1 1/4 and longer	49	.94	5.25

[1] Premiums and discounts in cents per pound from the price of Middling 7/8-inch cotton. The price of Middling 7/8-inch White cotton in the selected local markets averaged 17.86 cents per pound in 1928–29, 17.20 cents per pound in 1929–30, 9.74 cents per pound in 1930–31, 5.75 cents per pound in 1931–32, 6.21 cents per pound in 1932–33, and 13.73 cents per pound for the 5 seasons combined. Central-market quotations averaged 18.36, 17.58, 10.03, 5.84, 6.30, and 14.07 cents per pound, respectively. Data for these averages are confined largely to sales made during the first 8 or 9 months of the season.

[2] Includes Extra White cotton.

[3] Quotations for Middling 7/8-inch cotton (average for the 10 designated spot markets), average premiums for 15/16-inch and 1-inch cotton at the 6 spot markets, average premiums for 1 1/16-inch cotton and longer at Memphis and New Orleans, and average discount for 13/16-inch cotton at Houston, Galveston, and New Orleans were weighted by the number of bales of cotton of the same grade and staple-length designations sold on the same day and included in the sample of cotton shown for local markets.

[4] Bales sold in local markets when classed in odd-numbered thirty-seconds of an inch, have been tabulated as of the next lower sixteenth of an inch.

[5] 13/16-inch cotton only.

Average premiums for the longer staples and average discounts for the shorter staples in selected local markets for cotton of various grades differed somewhat from those for cotton Middling in grade

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(table 8). The influence of grade was largely eliminated by comparing prices of cotton of different staples but of the same grade, and by averaging the staple premiums and discounts for the higher grades with those for the lower grades. It should be stated that in central markets, staple premiums are generally somewhat greater for the higher grades than for the lower grades. Differences in average staple premiums and discounts for cotton of all grades from those for Middling may result from the failure of the larger staple premiums and discounts for the higher grade cotton to be counterbalanced by the smaller staple premiums and discounts for the lower grade cotton and vice versa.

TABLE 8.—*Average premiums and discounts* [1] *for specified staple lengths of various grades* [2] *of Extra White, White, and Spotted cotton in selected local markets, seasons 1928–29 to 1932–33*

SEASON 1928–29

Staple length (inches) [3]	Size of sample	Premiums and discounts (−)	Staple length (inches) [3]	Size of sample	Premiums and discounts (−)
	Bales	*Cents*		*Bales*	*Cents*
Shorter than 7/8	12,352	−0.06	1 1/16	3,511	0.36
7/8 (basis)	46,103	.00	1 1/8	1,652	.61
15/16	26,440	.04	1 3/16	491	.85
1	11,741	.12	1 1/4 and longer	95	.68

SEASON 1929–30

Shorter than 7/8	19,348	−0.08	1 1/16	2,556	0.46
7/8 (basis)	43,800	.00	1 1/8	895	.67
15/16	20,433	.07	1 3/16	99	.86
1	8,621	.14	1 1/4 and longer	10	1.08

SEASON 1930–31

Shorter than 7/8	6,539	−0.08	1 1/16	2,823	0.23
7/8 (basis)	30,520	.00	1 1/8	537	.22
15/16	24,530	.03	1 3/16	56	.18
1	10,971	.12	1 1/4 and longer	3	.50

SEASON 1931–32

Shorter than 7/8	1,255	−0.01	1 1/16	1,532	0.21
7/8 (basis)	8,922	.00	1 1/8	188	.28
15/16	9,418	.04	1 3/16	16	.83
1	5,434	.09			

SEASON 1932–33

Shorter than 7/8	1,177	−0.02	1 1/16	822	0.14
7/8 (basis)	12,065	.00	1 1/8	80	.20
15/16	9,843	.03	1 3/16	4	.22
1	4,233	.11			

TOTAL

Shorter than 7/8	40,671	−0.07	1 1/16	11,244	0.31
7/8 (basis)	141,410	.00	1 1/8	3,352	.54
15/16	90,664	.04	1 3/16	666	.79
1	41,000	.12	1 1/4 and longer	108	.71

[1] Premiums and discounts in cents per pound from the price of 7/8-inch cotton of the same grade. The price of 7/8-inch cotton of various grades in the selected local markets averaged 17.82 cents per pound in 1928–29, 17.08 cents per pound in 1929–30, 9.56 cents per pound in 1930–31, 5.61 cents per pound in 1931–32, 6.25 cents per pound in 1932–33, and 14.05 cents per pound for the 5 seasons combined. Data for these averages are confined largely to sales made during the first 8 or 9 months of the season.

[2] The influence of grade was largely eliminated by comparing prices of cotton of different staple lengths but of the same grade. Grades from Strict Good Middling White to Good Ordinary White and from Good Middling Spotted to Low Middling Spotted, inclusive, included.

[3] Bales sold in local markets, when classed in odd-numbered thirty-seconds of an inch, have been tabulated as of the next lower sixteenth of an inch.

Average staple premiums and discounts in local markets and those quoted in central markets varied somewhat irregularly from year to year, but, on the whole, these average premiums and discounts when expressed in cents a pound narrowed from 1928–29 and 1929–30 to 1932–33 along with the marked decline in cotton prices. When expressed as percentages of Middling ⅞-inch prices, however, staple premiums and discounts both in local and in central markets varied irregularly from year to year but were somewhat greater in 1931–32 than in the other years. That the irregular variations in staple premiums and discounts in local markets from year to year are not accounted for by the failure to include the same local markets in the study each year is indicated by the fact that average staple premiums and discounts for 13 selected markets included each year since 1928–29 also show irregularities that are more or less similar to those shown for all markets combined.

Average staple premiums and discounts made to growers also varied considerably from market to market. Differences between average staple premiums and discounts in individual local markets of the same type in many cases were as great as or greater than the differences between average staple premiums and discounts in local markets of different types. Furthermore, prices paid by buyers of different types revealed no consistent relationships between type of buyer and the average staple premiums and discounts made to growers. Average staple premiums and discounts in the selected local markets varied irregularly from month to month. However, the data for 1928–29 show some indication of increased staple premiums and discounts to growers as the season advanced, but for the other years no distinct indications of trends were in evidence.

The questions, What proportion of the central-market staple premiums and discounts are passed back to the farmer at his local selling point? and, To what extent do the premiums and discounts for individual-bale sales differ from the averages shown? are also important in connection with the average staple premiums and discounts shown.

In connection with the first question, it was found that for the 5-year period, on an average, premiums for staples longer than ⅞ inch in local markets amounted to only 17 percent of those quoted in central markets and varied from only 12 percent for 15/16-inch cotton to 34 percent for 1⅛-inch cotton. Discounts for cotton shorter than ⅞ inch in local markets amounted to only 6 percent of those quoted in central markets for cotton with a staple length of 13/16 inch. The proportion of central-market premiums for the longer staples and discounts for the shorter staples reflected in prices received by growers varied irregularly from year to year.

The extent to which staple premiums and discounts for individual bales differed from the averages is indicated by the data presented in table 9. An examination of these data shows that the average staple premiums and discounts (table 7) in many cases were less than the average variations in prices of individual bales of cotton of the same grade and staple length sold in the same local markets on the same days. Although the average prices received by growers for cotton shorter than ⅞ inch were somewhat higher than the average price received for ⅞-inch cotton of the same grade during the 5-year period studied, the prices received for 46 percent of the cotton shorter than ⅞ inch were actually higher than the average price received for ⅞-inch

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cotton of the same grade. Despite the fact that prices received by growers for staples longer than ⅞ inch averaged somewhat higher than those received for ⅞-inch cotton of the same grade, the prices received were actually lower than the average price received for ⅞-inch cotton of the same grade for 45 percent of the 15/16-inch cotton; 41 percent of the 1 inch; 32 percent of the 1 1/16 inch; 20 percent of the 1⅛ inch; 16 percent of the 1 3/16 inch; and 20 percent of the cotton 1¼ inches and longer. The distributions of variations in prices for each year were, in general, similar to those for the 5 years combined (table 21).

TABLE 9.—*Frequency distribution of variations in prices* [1] *per pound received by growers for individual bales of specified staple lengths of Middling White* [2] *cotton from the average price received for 7/8-inch cotton of the same grade in selected local markets, seasons 1928–29 to 1932–33, combined*

Variation (cents)	Shorter than 7/8 inch		7/8 inch		15/16 inch		1 inch		1 1/16 inches		1 1/8 inches		1 3/16 inches		1 1/4 inches and longer	
	Bales	*Percent*	*Bales*	*Percent*	*Bales*	*Percent*	*Bales*	*Percent*	*Bales*	*Percent*	*Bales*	*Percent*	*Bales*	*Percent*	*Bales*	*Percent*
Under −2.80	10	0.1	19	(3)	15	0.1	7	0.1								
−2.80 to −2.41	11	.1	13	(3)	19	.1	6	(3)	2	(3)						
−2.40 to −2.01	32	.3	39	0.1	39	.1	15	.1	5	0.1						
−2.00 to −1.61	46	.4	72	.2	76	.3	29	.2	17	.4	3	0.3				
−1.60 to −1.21	120	1.2	241	.6	205	.7	88	.7	37	.9	4	.3	2	0.9		
−1.20 to −0.81	399	3.9	883	2.0	678	2.4	290	2.2	94	2.2	18	1.5	3	1.4	1	2.0
−0.80 to −0.41	1,331	12.9	3,915	9.1	2,454	8.9	1,094	8.2	322	7.4	59	5.1	12	5.6	2	4.1
−0.40 to −0.01	3,666	35.5	15,554	36.1	8,885	32.1	3,901	29.2	915	21.0	149	12.7	18	8.3	7	14.3
0.00 to 0.39	3,284	31.8	17,446	40.5	10,687	38.5	4,789	35.9	1,352	31.0	270	23.1	35	16.2	12	24.4
0.40 to 0.79	999	9.7	3,956	9.2	3,552	12.8	2,051	15.4	829	19.0	218	18.6	40	18.5	4	8.2
0.80 to 1.19	279	2.7	744	1.7	805	2.9	725	5.4	426	9.8	157	13.4	32	14.8	4	8.2
1.20 to 1.59	91	.9	160	.4	203	.7	231	1.7	193	4.4	120	10.3	22	10.2	5	10.2
1.60 to 1.99	31	.3	34	.1	51	.2	70	.5	88	2.0	70	6.0	12	5.6	5	10.2
2.00 to 2.39	14	.1	12	(3)	23	.1	29	.2	38	.9	44	3.8	14	6.5	4	8.2
2.40 to 2.79	8	.1	8	(3)	17	.1	15	.1	21	.5	26	2.2	12	5.6		
2.80 to 3.19	3	(3)	3	(3)	7	(3)	4	(3)	8	.2	15	1.3	5	2.3	2	4.1
3.20 and over			5	(3)	10	(3)	5	(3)	10	.2	16	1.4	9	4.1	3	6.1
Total	10,324	100.0	43,104	100.0	27,726	100.0	13,349	100.0	4,357	100.0	1,169	100.0	216	100.0	49	100.0
	Cents		*Cents*		*Cents*		*Cents*		*Cents*		*Cents*		*Cents*		*Cents*	
Mean	−0.05		0.00		0.04		0.12		0.29		0.70		0.97		0.94	
Standard error of mean	.01		.00		.00		.00		.01		.03		.08		.16	
Average deviation	.39		.32		.36		.39		.50		.70		.86		.95	
Approximate range [4]	8.00		8.40		9.60		7.60		9.60		6.40		6.00		4.40	

[1] Minus sign (−) means below the average price for 7/8-inch White cotton.
[2] Extra White cotton included.
[3] Less than 0.05 percent.
[4] The approximate range was measured from the mid-point of the extreme classes.

FACTORS AFFECTING PREMIUMS AND DISCOUNTS FOR GRADE AND STAPLE LENGTH IN LOCAL MARKETS

Several factors may help to explain the failure of local-market premiums and discounts for grade and staple length to equal those quoted in central markets. These include differences in classification, differences in character of cotton, inadequate volume, risks from fluctuations in prices, and differences in bargaining power of growers.

DIFFERENCES IN CLASSIFICATION

The classification on the basis of which the cotton was sold in local markets was often considerably different from that designated by Government classers (tables 10 and 11). Data on cotton sold in the selected local markets for which the classifications of local buyers and of Government classers were available show that during the seasons 1928–29 to 1932–33, inclusive, local buyers' classifications averaged almost one-half grade lower and between one thirty-second and one-sixteenth inch longer in staple than those of Government classers. Local buyers' classification for 35 percent of the cotton was 1 grade below, for 7 percent was 2 grades below, and for less than 1 percent was 3 or more grades below Government classification; although local buyers' classification for about 12 percent of the cotton was 1 grade above and for about 1 percent was 2 or more grades above Government classification. Local buyers classed about 37 percent of this cotton one-sixteenth inch longer, 17 percent one-eighth inch longer, and 4 percent three-sixteenths inch or more longer than Government classers; but about 10 percent was classed as one-sixteenth inch shorter, and almost 2 percent was classed one-eighth inch or more shorter by local buyers than by Government classers.

TABLE 10.—*Differences between the grade of White cotton as classed by local buyers in selected local markets and the grade as indicated by Government classers, seasons 1928–29 to 1932–33* [1]

SEASON 1928–29

Grade	Size of sample		Proportion of cotton classed as higher grade by local buyers than by Government classers				Proportion of cotton classed as lower grade by local buyers than by Government classers			
	Government classification	Local buyers' classification	Total	One grade higher	Two grades higher	Three or more grades higher	Total	One grade lower	Two grades lower	Three or more grades lower
	Bales	*Bales*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
2, Strict Good Middling	60	-------	-------	-------	-------	-------	100.0	20.0	70.0	10.0
3, Good Middling	1,996	354	-------	-------	-------	-------	93.4	70.0	20.4	3.0
4, Strict Middling	6,216	4,429	3.1	3.1	-------	-------	59.1	46.9	11.7	.5
5, Middling	5,582	6,944	11.0	10.9	0.1	-------	37.1	32.9	3.8	.4
6, Strict Low Middling	2,171	3,932	29.8	27.8	2.0	-------	20.4	18.7	1.5	.2
7, Low Middling	541	930	58.2	38.6	19.0	0.6	5.2	4.6	.6	-------
8, Strict Good Ordinary	147	141	66.0	49.0	9.5	7.5	3.4	3.4	-------	-------
9, Good Ordinary	34	17	88.2	50.0	26.4	11.8	-------	-------	-------	-------

See footnotes at end of table.

TABLE 10.—*Differences between the grade of White cotton as classed by local buyers in selected local markets and the grade as indicated by Government classers, seasons 1928–29 to 1932–33* [1]—Continued

SEASON 1929–30

Grade	Size of sample		Proportion of cotton classed as higher grade by local buyers than by Government classers				Proportion of cotton classed as lower grade by local buyers than by Government classers			
	Government classification	Local buyers' classification	Total	One grade higher	Two grades higher	Three or more grades higher	Total	One grade lower	Two grades lower	Three or more grades lower
	Bales	*Bales*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
2, Strict Good Middling	5	------	------	------	------	------	100.0	20.0	20.0	60.0
3, Good Middling	667	223	------	------	------	------	98.7	33.7	61.9	3.1
4, Strict Middling	2,427	1,677	8.0	8.0	------	------	45.1	45.1	------	------
5, Middling	1,987	2,530	15.4	14.4	1.0	------	43.3	40.3	2.6	.4
6, Strict Low Middling	815	1,345	25.8	22.9	2.9	------	15.7	13.7	1.8	.2
7, Low Middling	223	250	27.3	21.5	5.8	------	39.5	32.3	7.2	------
8, Strict Good Ordinary	51	125	25.5	19.6	3.9	2.0	13.7	9.8	3.9	------
9, Good Ordinary	8	33	12.5	------	------	12.5	------	------	------	------

SEASON 1930–31

2, Strict Good Middling	3	------	------	------	------	------	100.0	------	100.0	------
3, Good Middling	701	173	------	------	------	------	92.3	85.0	7.1	0.2
4, Strict Middling	2,529	3,036	3.9	3.9	------	------	21.7	19.9	1.7	.1
5, Middling	1,365	1,348	41.0	39.5	1.5	------	10.4	10.1	.2	.1
6, Strict Low Middling	352	399	41.7	36.6	4.5	0.6	12.8	8.0	4.8	------
7, Low Middling	97	79	52.6	50.5	2.1	------	11.3	11.3	------	------
8, Strict Good Ordinary	21	37	85.7	47.6	33.3	4.8	------	------	------	------
9, Good Ordinary	4	------	100.0	50.0	------	50.0	------	------	------	------

SEASON 1931–32

3, Good Middling	303	133	------	------	------	------	87.8	55.1	32.7	------
4, Strict Middling	1,158	996	7.5	7.5	------	------	33.3	32.1	1.0	0.2
5, Middling	374	661	39.8	37.4	2.4	------	15.0	14.7	------	.3
6, Strict Low Middling	63	109	38.0	31.7	6.3	------	------	------	------	------
7, Low Middling	5	2	80.0	60.0	20.0	------	20.0	20.0	------	------
8, Strict Good Ordinary	------	1	------	------	------	------	------	------	------	------
9, Good Ordinary	------	1	------	------	------	------	------	------	------	------

SEASON 1932–33

3, Good Middling	12	3	------	------	------	------	100.0	91.7	8.3	------
4, Strict Middling	409	505	0.5	0.5	------	------	26.4	24.7	1.5	0.2
5, Middling	477	382	40.0	39.8	0.2	------	12.1	11.5	.4	.2
6, Strict Low Middling	118	118	44.9	40.7	4.2	------	15.2	14.4	------	.8
7, Low Middling	18	22	77.8	55.6	22.2	------	5.6	5.6	------	------
8, Strict Good Ordinary	------	2	------	------	------	------	------	------	------	------
9, Good Ordinary	------	2	------	------	------	------	------	------	------	------

TOTAL

2, Strict Good Middling	68	------	------	------	------	------	100.0	19.1	67.7	13.2
3, Good Middling	3,679	886	------	------	------	------	93.7	65.1	26.4	2.2
4, Strict Middling	12,739	10,643	4.5	4.5	------	------	45.6	39.1	6.2	.3
5, Middling	9,785	11,865	18.5	18.0	0.5	------	32.6	29.5	2.8	.3
6, Strict Low Middling	3,519	5,903	30.7	28.1	2.6	(2)	18.0	15.9	1.9	.2
7, Low Middling	884	1,283	50.2	36.1	13.8	0.3	14.6	12.4	2.2	------
8, Strict Good Ordinary	219	306	58.4	42.0	10.5	5.9	5.5	4.6	.9	------
9, Good Ordinary	46	53	76.1	41.3	19.6	15.2	------	------	------	------

[1] The samples classed by local buyers were generally cut from the bales, whereas most of the samples classed by Government classers were taken from the gin press box.
[2] Less than 0.05 percent.

TABLE 11.—*Differences in the staple length of White cotton as classed by local buyers in selected local markets from the staple length as indicated by Government classers, seasons 1928–29 to 1932–33* [1]

SEASON 1928–29

Staple length (inches)	Size of sample		Proportion of cotton classed as longer staple length by local buyers than by Government classers				Proportion of cotton classed as shorter staple length by local buyers than by Government classers			
	Government classification	Local buyers' classification	Total	1/16 inch longer	1/8 inch longer	3/16 inch plus longer	Total	1/16 inch shorter	1/8 inch shorter	3/16 inch shorter
	Bales	*Bales*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
Shorter than 7/8	409	117	93.4	46.5	29.8	17.1				
7/8	1,224	844	61.9	35.8	21.8	4.3	4.2	4.2		
15/16	1,238	1,149	48.5	38.6	8.6	1.3	17.9	15.8	2.1	
1	850	1,308	28.4	18.4	5.9	4.1	24.6	18.5	4.7	1.4
1-1/16	653	383	75.6	28.8	35.6	11.2	16.4	13.9	1.9	.6
1-1/8	969	683	67.6	48.6	19.0		2.9	1.4	1.0	.5
1-3/16	551	1,104	27.4	27.4			20.3	20.3		
1-1/4 and longer	132	438					81.8	61.4	20.4	
SEASON 1929–30										
Shorter than 7/8	804	93	66.1	34.7	15.3	16.1				
7/8	535	553	72.2	22.1	44.5	5.6	1.7	1.7		
15/16	208	314	73.5	46.6	9.1	17.8	16.3	14.4	1.9	
1	242	660	74.3	9.5	41.7	23.1	2.9	2.1	.8	
1-1/16	696	117	84.0	48.7	34.9	.4	12.1	11.8	.2	0.1
1-1/8	840	799	61.3	60.5	.8		5.5	1.7	3.8	
1-3/16	200	985	1.0	1.0			19.0	18.5		.5
1-1/4 and longer	9	13					100.0	55.6	33.3	11.1
SEASON 1930–31										
Shorter than 7/8	2		100.0	50.0	50.0					
7/8	22	19	77.2	31.8	40.9	4.5				
15/16	49	21	59.2	49.0	10.2		22.4	22.4		
1	20	42	35.0	35.0			25.0	20.0	5.0	
1-1/16	4	15					50.0	25.0		25.0
SEASON 1931–32										
Shorter than 7/8	33	3	100.0	39.4	33.3	27.3				
7/8	491	119	88.6	30.8	57.4	.4				
15/16	821	406	73.0	71.5	1.2	.3	4.9	4.6	0.3	
1	470	1,287	5.9	5.5	.4		15.5	13.0	2.3	0.2
1-1/16	51	51	5.9	5.9			74.6	70.6	2.0	2.0
1-1/8	8	10					75.0	25.0	50.0	
1-3/16	2						100.0	50.0	50.0	
SEASON 1932–33										
Shorter than 7/8	4	4	75.0	25.0	25.0	25.0				
7/8	203	87	77.3	45.8	31.5		1.5	1.5		
15/16	458	438	45.0	45.0			7.4	7.4		
1	353	533	.6	.6			37.1	34.6	2.5	
1-1/16	40	3					100.0	90.0	10.0	
1-1/8	7						100.0	14.3	85.7	
TOTAL										
Shorter than 7/8	1,252	217	91.4	46.7	24.2	20.5				
7/8	2,475	1,622	70.8	32.6	34.7	3.5	2.6	2.6		
15/16	2,774	2,328	57.2	50.2	5.0	2.0	12.3	11.1	1.2	
1	1,935	3,830	23.7	11.1	7.9	4.7	22.0	18.0	3.3	0.7
1-1/16	1,444	569	74.9	36.7	33.0	5.2	18.8	17.0	1.3	.5
1-1/8	1,824	1,492	64.2	53.7	10.5		4.8	1.6	2.9	.3
1-3/16	753	2,089	20.3	20.3			20.1	19.9	.1	.1
1-1/4 and longer	141	451					83.0	61.0	21.3	.7

[1] The samples classed by local buyers were generally cut from the bales, whereas most of the samples classed by Government classers were taken from the gin press box.

Classifications made by local buyers were lower than those made by Government classers for a considerable proportion of the higher grade and longer staple cotton and were higher than Government classification for a considerable proportion of the lower grade and shorter staple cotton (tables 10 and 11). The proportions of the cotton of the various grades as classed by Government classers that were given a lower grade by local buyers varied from 100 percent for Strict Good Middling to 0 for Good Ordinary; and the proportions that were given a higher grade by local buyers varied from 76 percent for Good Ordinary to 0 for Good Middling and Strict Good Middling. The proportions of cotton of the various staple lengths as classed by Government classers that were classed as longer in staple by local buyers varied from 91 percent for staples shorter than ⅞ inch to 0 for staples 1¼ inches long and longer; and the proportions that were classed as shorter by local buyers varied from 83 percent for staples 1¼ inches long and longer to 0 for staples shorter than ⅞ inch. Obviously the staple-length group 1¼ inches long and longer could not be raised and the staple-length group shorter than ⅞ inch could not be lowered, because all the cotton with staples 1¼ inches long and longer or shorter than ⅞ inch, respectively, were included in these groups.

Differences between the classification of local buyers and that of Government classers may be the result of a number of factors. The classification of cotton is not an exact science, but an art, and is subject to considerable subjective error on the part of all classers. Balls (*4, pp. 3–4*) states:

> Thus I have seen so much of the grader's skill, and that under circumstances which tested his skill far more severely than daily routine, as to have no doubt whatever that the decisions of the grader are real evaluations of certain properties possessed by cotton. Such properties are perceptible by many persons, are appreciable by fewer, and the appreciation is capable of practical use only by those who combine perception and appreciation with years of daily experience. Tactile and muscular perceptions are employed, as well as sight, and the impressions yielded by each are integrated, consciously and subconsciously, into a recognition of the individuality of each sample, which then is stored in the memory. It is not surprising that such a complex mental process should easily be thrown off its balance by having to work in a strange light, or by unusual amounts of moisture in the cotton; most students of the crop have known a grader who praised and purchased a damp sample, though casting out a duplicate which had been dried. It cannot be expected that grading should be infallible. Even now, when we have material for measuring the degree of its fallibility, we may well be surprised that its errors are not greater; compare it with the error involved in judging the weight of an animal, which is comparatively child's play.

Many of the local buyers were not thoroughly trained cotton classers and were not familiar with the official cotton standards. The conditions under which the local buyers classed much of the cotton were not conducive to accurate classification on the basis of the official standards. The samples on the basis of which most of this cotton was sold were cut from the bales, whereas the samples on which the classifications of Government classers were based were loose samples taken at the gin press box. Where the cotton is not uniform in quality throughout the bale a sample taken from the press box and one cut from the bale may show differences in grade and staple length as a result of having been taken from different parts of the bale and/or of possible differences in physical condition.

Differences in classification upon the basis of which the cotton was sold, from that upon the basis of which premiums and discounts were calculated, affect materially the average premiums and dis-

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counts for grade and staple length shown. For example, if full central-market premiums and discounts on the basis of local buyers' classification (tables 10 and 11) had been made to growers when premiums and discounts for the same cotton were calculated on the basis of Government classification (tables 10 and 11), the average premiums and discounts shown for the various grades would have amounted to the following percentages of those quoted in central markets:

	Percent		Percent
Strict Good Middling	75	Low Middling	62
Good Middling	89	Strict Good Ordinary	65
Strict Middling	115	Good Ordinary	62
Strict Low Middling	65		

Average premiums and discounts shown for the various staples would have amounted to the following percentages of those quoted in central markets:

	Percent		Percent
13/16 inch	27	1⅛ inches	117
15/16 inch	61	1 3/16 inches	94
1 inch	66	1¼ inches	52
1 1/16 inches	122		

That these differences in premiums and discounts are not entirely due to possible inaccuracies in the classification of local buyers is indicated by a comparison of the premiums and discounts for grade and staple length based on two classifications of 3,776 bales in 1930–31 made by Government experts. For example, when full central-market premiums and discounts were applied to the classification by Government experts of samples cut from the compressed bales and when the premiums and discounts for the same bales were calculated on the basis of Government classification of loose samples taken at the gin press box, the average premiums and discounts shown for the various grades amounted to the following percentages of those quoted in central markets:

	Percent		Percent
Good Middling	75	Low Middling	68
Strict Middling	75	Strict Good Ordinary	84
Strict Low Middling	69	Good Ordinary	101

Average premiums and discounts for the various staples amounted to the following percentages of those quoted in central markets:

	Percent		Percent
13/16 inch	42	1 1/16 inches	82
15/16 inch	92	1⅛ inches	88
1 inch	90		

The differences in premiums and discounts resulting from differences in classification can be explained only in part by differences in the samples resulting from their having been taken from different parts of the bale and by possible differences in the physical conditions of the samples as a result of compression. A comparison of the classifications of split samples from over 4,000 bales by Government experts shows significant differences. For example, when full central-market premiums and discounts were applied to this cotton on the basis of the classification of one set of samples and the premiums and discounts for the same bales were calculated on the basis of the classification of the other set of samples, the average premiums and

discounts shown for the various grades amounted to the following percentages of the premiums and discounts quoted in central markets:

	Percent		Percent
Strict Good Middling	76	Low Middling	87
Good Middling	86	Strict Good Ordinary	91
Strict Middling	96	Good Ordinary	90
Strict Low Middling	76		

Average premiums and discounts shown for the various staples amounted to the following percentages of the premiums and discounts quoted in central markets:

	Percent		Percent
13/16 inch	45	1 1/8 inches	90
15/16 inch	81	1 3/16 inches	77
1 inch	70	1 1/4 inches	51
1 1/16 inches	88		

Average premiums and discounts made to growers on the basis of local buyers' classification were considerably greater than those shown on the basis of the classification of Government classers, but were considerably less than those quoted in central markets (tables 12 and 13). The average premiums received by growers, on the basis of local buyers' classification, for grades above Middling, amounted to 64 percent of those quoted in central markets, whereas on the basis of Government classification the premiums received by growers amounted to only 46 percent of those quoted in central markets.

TABLE 12.—*Average premiums and discounts* [1] *for specified grades of White cotton of 7/8-inch staple length in selected local markets on the basis of local buyers' classifications, seasons 1928–29 and 1929–30*

SEASON 1928–29

Grade	Size of sample	Premiums and discounts (−)	Grade	Size of sample	Premiums and discounts (−)
	Bales	*Cents*		*Bales*	*Cents*
3, Good Middling	81	0.29	7, Low Middling	2	−1.42
4, Strict Middling	336	.20	8, Strict Good Ordinary		
5, Middling (basis)	294	.00	9, Good Ordinary	12	−2.14
6, Strict Low Middling	95	−.54			

SEASON 1929–30

4, Strict Middling	86	0.01	6, Strict Low Middling	16	−.73
5, Middling (basis)	347	.00			

TOTAL

3, Good Middling	81	0.29	7, Low Middling	2	−1.42
4, Strict Middling	422	.16	8, Strict Good Ordinary		
5, Middling (basis)	641	.00	9, Good Ordinary	12	−2.14
6, Strict Low Middling	111	−.57			

[1] Premiums and discounts in cents per pound from the price of Middling 7/8-inch White cotton. The price of Middling 7/8-inch White cotton in the selected local markets averaged 17.91 cents per pound in 1928–29, 17.66 cents per pound in 1929–30, and 17.77 cents per pound for the 2 seasons combined. Data for these averages are confined largely to sales made during the first 8 or 9 months of the season.

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TABLE 13.—*Average premiums and discounts* [1] *for specified staple lengths of Middling White cotton in selected local markets on the basis of local buyers' classification, seasons 1928–29 and 1929–30*

Staple length (inches)	Size of sample	Premiums and discounts (−)	Staple length (inches)	Size of sample	Premiums and discounts (−)
	SEASON 1928–29				
	Bales	*Cents*		*Bales*	*Cents*
Shorter than 7/8	10	−0.13	1	26	−0.66
7/8 (basis)	294	.00	1 1/16	6	1.07
15/16	168	.06	1 1/8	2	1.41
	SEASON 1929–30				
Shorter than 7/8	76	−0.86	1	302	−0.73
7/8 (basis)	347	.00	1 1/16	49	1.23
15/16	220	.34	1 1/8	12	1.53
	TOTAL				
Shorter than 7/8	86	−0.78	1	328	−0.72
7/8 (basis)	641	.00	1 1/16	55	1.21
15/16	388	.22	1 1/8	14	1.51

[1] Premiums and discounts in cents per pound from the price of Middling 7/8-inch cotton. The price of Middling 7/8-inch White cotton in the selected local markets averaged 17.91 cents per pound in 1928–29, 17.66 cents per pound in 1929–30, and 17.77 cents per pound for the 2 seasons combined. Data for these averages are confined largely to sales made during the first 8 or 9 months of the season.

The discounts made to growers for White grades below Middling on the basis of local buyers' classification amounted to 70 percent of those quoted in central markets, whereas on the basis of Government classification the discounts made to growers for this lower-grade cotton amounted to only 58 percent of those quoted in central markets. The discounts made to growers for cotton with staples shorter than 7/8 inch, on the basis of local buyers' classification, amounted to 92 percent of those quoted in central markets, while on the basis of Government classification the discounts made to growers for this short cotton amounted to less than 7 percent of those quoted in central markets.

Premiums received by growers on the basis of local buyers' classification for the longer staples amounted to 65 percent of those quoted in central markets, but on the basis of Government classification the premiums received by growers amounted to only 18 percent of those quoted in central markets.

Although the size of the sample used in this study of premiums and discounts made to growers on the basis of local buyers' classification was relatively small and was confined to only eight local markets, the results are considered significant. The data indicate that the differences in classification accounted for a considerable part of the apparent failure of prices received by growers to reflect premiums and discounts for grade and staple length equal to those quoted in central markets.

Less irregular variations in prices received by growers with the grade and staple length of the cotton were shown on the basis of local buyers' classification than on the basis of Government classification (tables 14 and 15). Although the irregular variations in prices received by growers on the basis of local buyers' classifications were considerably less than those received on the basis of Government classification, in many cases they were considerably greater than the average premiums and discounts for grade and staple length made to growers.

TABLE 14.—*Frequency distribution of variations in prices [1] per pound received by growers for individual bales of specified grades of White cotton of 7/8-inch staple from the average price received for Middling White cotton of the same staple length in selected local markets, on the basis of local buyers' classifications, seasons 1928–29 and 1929–30 combined*

Variation (cents)	3, Good Middling		4, Strict Middling		5, Middling		6, Strict Low Middling		7, Low Middling	
	Bales	*Percent*	*Bales*	*Percent*	*Bales*	*Percent*	*Bales*	*Percent*	*Bales*	*Percent*
Under −1.60							1	0.9	1	50.0
−1.60 to −1.21					1	0.2	4	3.6	1	50.0
−1.20 to −0.81			2	0.5	3	.5	24	21.6		
−0.80 to −0.41	1	1.2	9	2.1	38	5.9	57	51.4		
−0.40 to −0.01	16	19.8	72	17.1	303	47.3	14	12.6		
0.00 to 0.39	43	53.1	296	70.1	257	40.1	7	6.3		
0.40 to 0.79	10	12.3	31	7.4	32	5.0	3	2.7		
0.80 to 1.19	7	8.6	10	2.4	2	.3	1	.9		
1.20 to 1.59	2	2.5	1	.2	2	.3				
1.60 to 1.99	2	2.5	1	.2	2	.3				
2.00 and over					1	.1				
Total	81	100.0	422	100.0	641	100.0	111	100.0	2	100.0
	Cents		*Cents*		*Cents*		*Cents*		*Cents*	
Mean	0.29		0.16		0.00		−0.57		−1.42	
Standard error of mean	.05		.01		.00		.04			
Average deviation	.32		.17		.26		.29		.20	
Approximate range [2]	2.40		2.80		3.60		2.80		.40	

[1] Minus sign (−) means below the average price for Middling White cotton.
[2] The approximate range was measured from the mid-point of the extreme classes.

TABLE 15.—*Frequency distribution of variations in prices [1] per pound received by growers for individual bales of specified staple lengths of Middling White cotton from the average price received for 7/8-inch cotton of the same grade in selected local markets, on the basis of local buyers' classifications, seasons 1928–29 and 1929–30 combined*

Variation (cents)	Shorter than 7/8 inch		7/8 inch		15/16 inch		1 inch		1 1/16 inches		1 1/8 inches	
	Bales	*Percent*	*Bales*	*Percent*	*Bales*	*Percent*	*Bales*	*Percent*	*Bales*	*Percent*	*Bales*	*Percent*
Under −2.00	1	1.2										
−2.00 to −1.61	5	5.8										
−1.60 to −1.21	10	11.6	1	0.2								
−1.20 to −0.81	25	29.1	3	.5	1	0.2						
−0.80 to −0.41	21	24.4	38	5.9	19	4.9						
−0.40 to −0.01	20	23.3	303	47.3	59	15.2	14	4.3	2	3.6		
0.00 to 0.39	4	4.6	257	40.1	209	53.9	41	12.5	1	1.8		
0.40 to 0.79			32	5.0	92	23.7	148	45.1	4	7.3	1	7.1
0.80 to 1.19			2	.3	7	1.8	91	27.8	15	27.3	1	7.1
1.20 to 1.59			2	.3			29	8.8	24	43.6	4	28.6
1.60 to 1.99			2	.3	1	.3	5	1.5	8	14.6	8	57.2
2.00 to 2.39			1	.1								
2.40 and over									1	1.8		
Total	86	100.0	641	100.0	388	100.0	328	100.0	55	100.0	14	100.0
	Cents		*Cents*		*Cents*		*Cents*		*Cents*		*Cents*	
Mean	−0.78		0.00		0.22		0.72		1.21		1.51	
Standard error of mean	.01		.00		.02		.02		.06		.10	
Average deviation	.44		.26		.23		.31		.36		.30	
Approximate range [2]	2.20		3.60		2.80		2.00		2.80		1.20	

[1] Minus sign (−) means below the average price for 7/8-inch White cotton.
[2] The approximate range was measured from the mid-point of the extreme classes.

It is not known to what extent the greater premiums and discounts result from bias on the part of local buyers, subjective errors which apply to all classers, differences in the physical condition of the samples and other factors. Although the calculation of premiums and

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discounts on the basis of a classification different from that upon which the cotton was sold affects the premiums and discounts shown, even when the two classifications are equally reliable, the available data are not adequate for making adjustments for the influences of these variations in classification on the premiums and discounts made to growers, as shown in tables 4, 5, 7, and 8. Available data do indicate, however, that adjustments for the influence of these differences in classification in many cases would result in increased premiums and discounts shown.

DIFFERENCES IN CHARACTER OF COTTON

Prices of cotton of the same grade and staple-length designation sold in the same market on the same day may also differ as a result of differences in character. In the absence of standards for character no attempt was made to determine to what extent differences in prices received by growers resulted from differences in the character of cotton. The limited information available indicates, however, that only a part of the differences in prices noted could be attributed to differences in the character of the cotton.

INADEQUATE VOLUME

Cotton of the higher grades and longer staples could not always be had in sufficient quantities in local markets to justify local buyers in paying the same premiums for grade and staple length that were paid for similar qualities of cotton sold in even-running lots in the central markets. Nevertheless, since the sale of small quantities of the lower grades and shorter staples (too small to be handled economically) have a tendency to increase the discounts for this cotton, they do not help to explain the failure of the local buyers to discount it as much as cotton of the same description was discounted in central markets.

RISKS FROM FLUCTUATIONS IN PRICES

Fluctuations in central-market premiums and discounts for grade and staple length increase the risk that buyers in local markets must assume and may account in part for the failure of central-market premiums and discounts to be more fully reflected in the prices paid to growers.

Fluctuations in cotton prices in local markets during the day result in irregular variations in the prices received by growers on the basis of the grade and staple length of cotton sold. It is believed that these irregular variations tend to compensate each other when averaged and that only a small part, if any, of the failure of average prices in local markets to reflect greater proportions of central-market premiums and discounts is thus accounted for. A part of the irregular variations shown in frequency distributions of variations in prices, however, may be accounted for by changes in prices during the day.

DIFFERENCES IN BARGAINING POWER

Differences in bargaining power of farmers and local buyers doubtless account for at least a part of the wide and irregular variations in prices received by growers for cotton of the same grade and staple length sold in the same local market on the same day. Differences in

bargaining power result from differences in general business ability, from differences in knowledge of the quality and commercial value of cotton, from differences in financial obligations, etc. For example, it was found that in a selected local market in Georgia in 1928 one buyer paid his tenant as much as 4.25 cents a pound more than he paid another farmer for cotton of the same grade as classed by the local buyer and of the same grade and staple length as classed by Government classers.

This instance may be a rather extreme one, but many somewhat smaller variations were noted. Some farmers were in debt to the local buyers and for that reason may have been able to exact relatively high prices for their cotton because of the buyers' willingness to pay relatively high prices in order to collect on accounts, whereas farmers who were obligated to sell their cotton to specific buyers may have been forced to take less than the prevailing market price for their cotton. Some buyers who were purchasing cotton as a means of collecting debts, or to increase their volume of business, may have been able to pay a considerably higher price for cotton than other buyers not similarly situated. Irregular variations in prices as a result of differences in bargaining power tend to compensate each other when averaged, but differences in bargaining power no doubt account for a considerable proportion of the irregular variations shown.

RELATION BETWEEN AVERAGE PRICES AND AVERAGE GRADE AND STAPLE LENGTH

FROM MARKET TO MARKET

Another phase of this study was to determine to what extent the average prices received by growers in different local markets reflected the average quality of the cotton sold in these markets as indicated by grade and staple length. Premiums and discounts for grade and staple length represent the average differences in prices received for other grades as compared with the average prices received for Middling White cotton of the same staple length and the average differences in prices received for other staple lengths as compared with the average prices received for ⅞-inch cotton of the same grade sold in the same local markets, with the influence of difference in date of sale largely eliminated. These differences were found to be more or less independent of the average level of prices in these markets. Consequently, they do not indicate to what extent the average prices received by growers in the various local markets varied with the average grade and staple length of the cotton sold in each of these markets.

Average prices paid in different local markets may reflect differences in the average quality of the cotton sold in these markets, even though prices paid for individual bales do not vary appreciably with the grade and staple length. To the extent that the average prices of cotton in different markets reflect the average quality of the cotton sold in these markets, the production of cotton of the higher grades and longer staples is rewarded on a community basis. To determine the extent to which the production of cotton of higher grade and longer staple was rewarded on a community basis, comparisons were

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made of the differences in average prices[8] received by growers in local markets with differences in average central-market values of the cotton resulting from differences in grade and staple length.[9]

The results show that in general during the period 1928–29 to

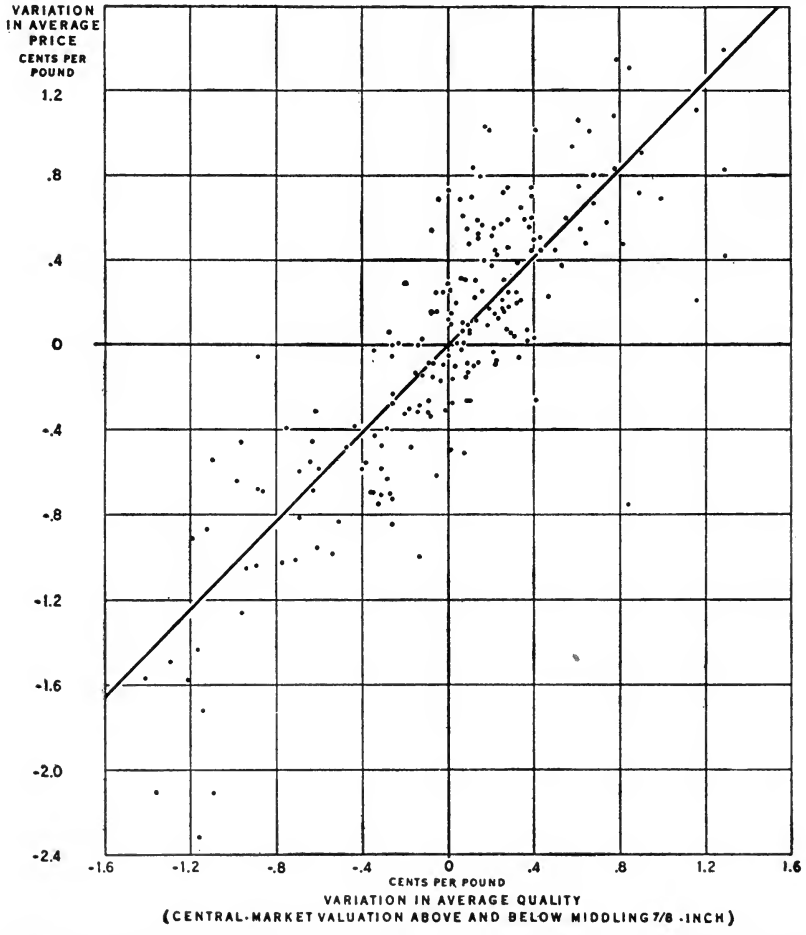

FIGURE 4.—RELATION OF AVERAGE PRICE TO AVERAGE QUALITY OF COTTON IN SELECTED LOCAL MARKETS IN TEXAS AND OKLAHOMA, SEASONS 1928–29 TO 1932–33, INCLUSIVE.

For the most part the average price received by growers in local markets where cotton of higher grade and longer staple was sold was somewhat higher than the average price received by growers in local markets where cotton of lower grade and shorter staple was sold, adjustments having been made for differences in cost of transportation to Houston, Tex. The coefficient of correlation amounted to 0.83 ± 0.02.

1932–33, the average prices received by growers in the selected local markets where the cotton averaged higher in grade and longer in staple were somewhat higher than the average prices received by growers in local markets where the cotton averaged lower in grade

[8] Adjustments were made in average local-market prices in Texas and Oklahoma for differences in costs of compression and freight to Houston; and in Arkansas, Tennessee, Mississippi, and Louisiana for differences in costs of compression and freight to New Orleans. No adjustments were made in the average prices in local markets in mill sections of North Carolina, South Carolina, Alabama, and Georgia (p. 51).

[9] Differences in average central-market values of the cotton sold in these markets were arrived at by weighting the number of bales of each grade and staple length by the central-market premiums and discounts.

and shorter in staple (figs. 4, 5, and 6). These differences in average prices were great enough in many cases to equal the premiums and discounts for grade and staple length quoted in central markets. In other words, farmers who sold cotton in local markets where the average quality as indicated by grade and staple length was relatively

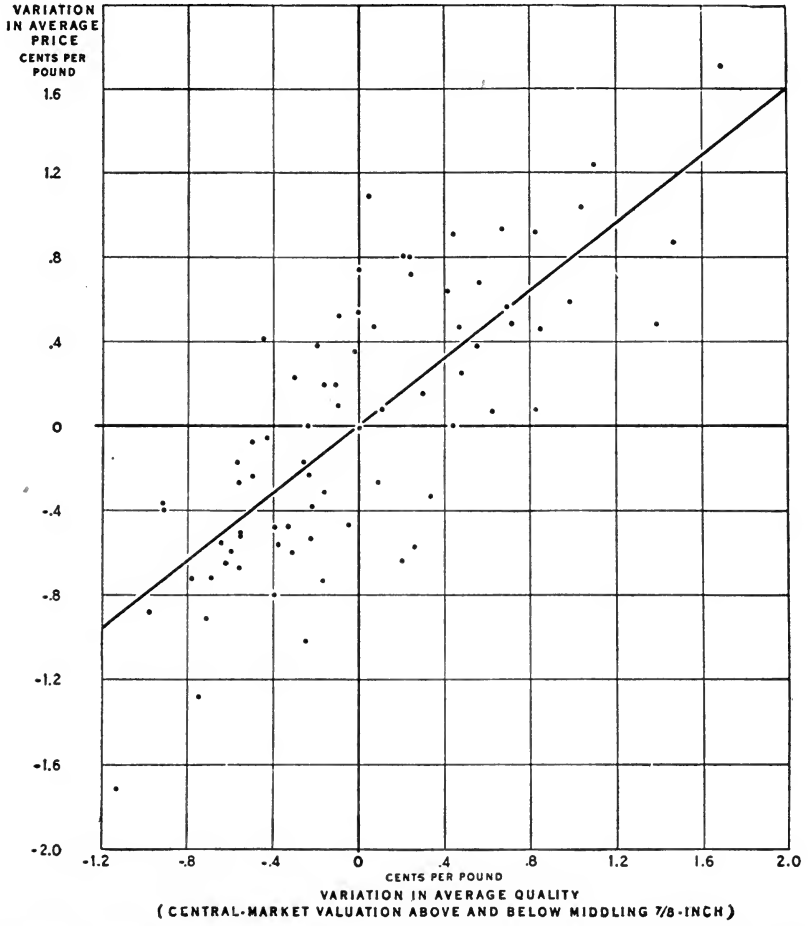

FIGURE 5.—RELATION OF AVERAGE PRICE TO AVERAGE QUALITY OF COTTON IN SELECTED LOCAL MARKETS IN ARKANSAS, LOUISIANA, MISSISSIPPI, AND TENNESSEE, SEASONS 1928–29 TO 1930–31, INCLUSIVE.

For the most part the average price received by growers in local markets where cotton of higher grade and longer staple was sold was somewhat higher than the average price received by growers in local markets where cotton of lower grade and shorter staple was sold, adjustments having been made for differences in cost of transportation to New Orleans, La. The coefficient of correlation amounted to 0.77 ± 0.05.

high received, on an average, correspondingly higher prices than those who sold cotton in local markets where the average quality of the cotton was relatively low.

Considerable irregularity was found in the relationship of average prices received by growers for cotton sold in different local markets to the average central-market value of this cotton. The coefficient of determination shows that, on an average, for the period 1928–29 to

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1932–33, 69 percent of the differences in averaged prices received in the specified local markets in Texas and Oklahoma combined was accounted for by differences in central-market value of the cotton sold in these markets. The corresponding percentage for Arkansas, Louisiana, Tennessee, and Mississippi combined was found to be 59; and that for North Carolina, South Carolina, Georgia, and

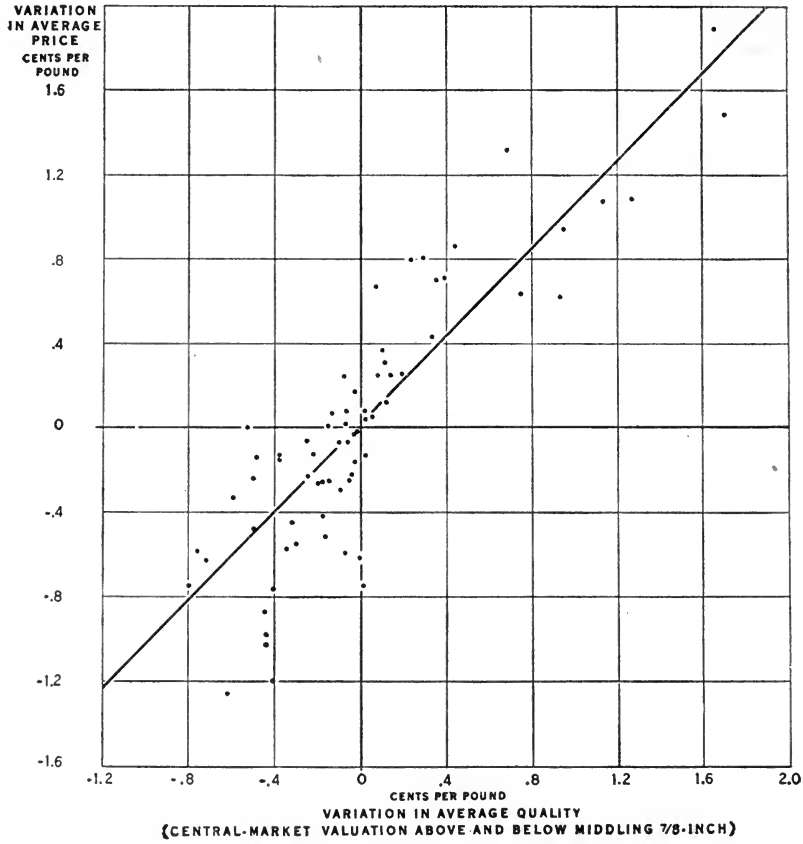

FIGURE 6.—RELATION OF AVERAGE PRICE TO AVERAGE QUALITY OF COTTON IN SELECTED LOCAL MARKETS IN ALABAMA, GEORGIA, NORTH CAROLINA, AND SOUTH CAROLINA, SEASONS 1928–29 TO 1930–31, INCLUSIVE.

For the most part the average price received by growers in local markets where cotton of higher grade and longer staple was sold was somewhat higher than the average price received by growers in local markets where cotton of lower grade and shorter staple was sold. The coefficient of correlation amounted to 0.87 ± 0.03.

Alabama combined, 76. This means that during the period covered for Texas and Oklahoma, 31 percent; for Arkansas, Louisiana, and Mississippi, 41 percent; and for North Carolina, South Carolina, Georgia, and Alabama, 24 percent of the differences in average prices in selected local markets were due to factors other than differences in average grade and staple length and in cost of carrying cotton from local to central markets.

It is realized, of course, that conditions in local markets—such as differences in the kind and extent of local competition, differences in

outlet for cotton, differences in weight on which the cotton was sold, differences in the bargaining power of farmers and of local buyers, and differences in the character of the cotton—may greatly influence average prices received by growers in these local markets.

The analysis indicates that differences in central-market values as a result of differences in staple length were on the whole of relatively greater importance in determining the average price level in local markets than were differences in central-market value due to differences in grade. Differences in central-market value due to differences in staple length were generally somewhat greater than differences in central-market value due to differences in grade, particularly in the States east of Texas and Oklahoma.

FROM MONTH TO MONTH

Average prices to growers in local markets reflected differences in average quality as indicated by grade and staple length from month to month, as well as from market to market. During months when the average quality as indicated by grade and staple length was relatively high, the average price received by growers in local markets was for the most part correspondingly higher, in relation to the price of Middling ⅞-inch cotton in central markets, than during months when the average quality as indicated by grade and staple length was relatively low.

Monthly average prices received by growers in selected local markets during the seasons 1928–29 to 1932–33 were higher, for the most part, as compared with central-market prices during the first part of the season than during the later part of the season (table 16 and figs. 7 and 8).[10] These relatively high local-market prices during the first part of the season may be accounted for in part by the larger volume of sales, which made it possible to handle cotton on relatively narrow margins and by competition of buyers, who having sold in advance, were in need of cotton with which to fulfill their commitments.

TABLE 16.—*Average price per pound paid for cotton in selected local markets* [1] *and in central markets,*[2] *by months, seasons 1928–29 to 1932–33*

SEASON 1928–29

Month	Middling ⅞-inch White [3] cotton			Various grades and staple lengths of White [3] and Spotted cotton		
	Size of sample [4]	Local-market price	Central-market price	Size of sample [5]	Local-market price	Central-market price
	Bales	*Cents*	*Cents*	*Bales*	*Cents*	*Cents*
August	242	18.11	18.43	3,538	18.26	18.92
September	2,703	17.15	17.58	27,819	17.52	18.10
October	4,400	18.10	18.45	40,094	18.30	18.67
November	2,951	18.01	18.67	21,590	18.10	18.75
December	865	18.17	19.08	10,125	17.68	18.58
January	123	17.85	18.87	2,414	16.73	18.48
February	48	17.98	18.85	575	16.26	17.82
March	40	18.92	19.81	396	17.02	18.93
April	4	18.58	19.24	7	18.34	19.06
Total	11,376	17.86	18.36	106,558	17.94	18.53

See footnotes at end of table.

[10] The influences of differences in price level in different local markets, together with monthly changes in the proportion of the total sample coming from different local markets, on the variations in monthly average prices in all local markets combined, were eliminated. Central-market prices represent average prices at the 10 designated spot markets on each day, weighted by the number of bales of cotton of the same description sold on the same day and included in the sample of cotton sold in the selected local markets.

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TABLE 16.—*Average price per pound paid for cotton in selected local markets and in central markets, by months, seasons 1928–29 to 1932–33*—Continued

SEASON 1929–30

Month	Middling 7/8-inch White [3] cotton			Various grades and staple lengths of White [3] and Spotted cotton		
	Size of sample [4]	Local-market price	Central-market price	Size of sample [5]	Local-market price	Central-market price
	Bales	*Cents*	*Cents*	*Bales*	*Cents*	*Cents*
August	1,686	17.67	18.00	12,347	17.97	18.51
September	3,927	17.75	17.96	29,492	17.98	18.18
October	5,719	17.29	17.65	34,685	17.25	17.49
November	2,195	16.20	16.73	13,279	15.76	16.16
December	565	15.58	16.66	6,741	14.62	15.48
January	106	15.44	16.54	1,778	13.79	15.19
February	31	14.38	15.26	678	13.83	15.52
March	9	13.63	14.65	136	11.57	12.95
April				10	14.17	15.32
Total	14,238	17.20	17.58	99,146	17.08	17.45

SEASON 1930–31

August	1,041	10.43	10.71	11,515	11.05	11.67
September	3,450	9.93	10.12	25,626	10.10	10.44
October	4,011	9.44	9.79	25,694	9.42	9.87
November	1,345	9.79	10.12	12,317	9.63	10.00
December	216	8.81	9.35	3,466	8.21	8.84
January	75	8.87	9.36	813	8.27	9.00
February	55	9.81	10.02	473	9.45	10.04
March	19	9.91	10.22	156	10.00	10.67
Total	10,212	9.74	10.03	80,060	9.84	10.28

SEASON 1931–32

August	13	6.47	6.38	259	6.40	7.00
September	625	5.74	5.74	7,417	5.85	6.25
October	1,372	5.63	5.76	11,606	5.60	6.00
November	705	5.95	6.05	6,166	6.01	6.19
December	153	5.70	5.74	2,024	5.38	5.68
January	30	6.00	6.15	801	5.35	5.94
February	10	6.29	6.51	316	5.46	6.17
March	5	6.39	6.54	247	6.07	6.88
Total	2,913	5.75	5.84	28,836	5.74	6.10

SEASON 1932–33

August	192	7.92	7.91	1,359	7.24	7.50
September	989	6.17	6.18	6,641	7.27	7.42
October	1,986	6.31	6.38	11,715	6.38	6.57
November	857	5.88	6.07	7,321	5.46	5.77
December	193	5.42	5.67	2,122	5.32	5.62
January	86	5.72	6.02	1,119	5.40	5.83
February	18	5.66	5.81	199	5.20	5.53
March	5	6.14	6.29	57	6.35	6.52
April	3	6.45	6.92	36	6.85	7.42
May	7	8.94	9.09	27	8.89	9.18
Total	4,336	6.21	6.30	30,596	6.28	6.51

[1] The influence of differences in price level in different local markets, together with variations in the proportion of the total sample coming from different local markets on monthly variations in average price were eliminated. (See appendix, p. 51, for method.)

[2] Central market prices for Middling 7/8-inch cotton are averages of quotations at the 10 designated spot markets. Central market prices for cotton of grades and staple lengths other than Middling 7/8-inch were obtained by applying to the average price of Middling 7/8-inch cotton at the 10 spot markets, average premiums and discounts for grade at the 10 designated spot markets; average premiums for 1 5/16-inch and 1-inch at the 6 spot markets (Dallas, Houston, Galveston, New Orleans, Memphis, and Little Rock); average premiums for lengths 1 1/16 inches and longer at Memphis and New Orleans; and average discounts for 1 3/16-inch staple at New Orleans, Houston, and Galveston. The premiums and discounts for grade are for 7/8-inch staple length and the premiums and discounts for staple are for Middling grade. These daily central market prices were weighted by the number of bales of cotton of the same description sold on the same day and included in the sample of cotton sold in the selected local markets.

[3] Extra White cotton included.

[4] 1 bale sold in July 1928, 26 bales sold in July and April 1929, and 2 bales sold in July 1930, not included.

[5] 45 bales sold in July 1928, 347 bales sold in July 1929, 665 bales sold in July 1930, and 166 bales sold in July 1932, not included.

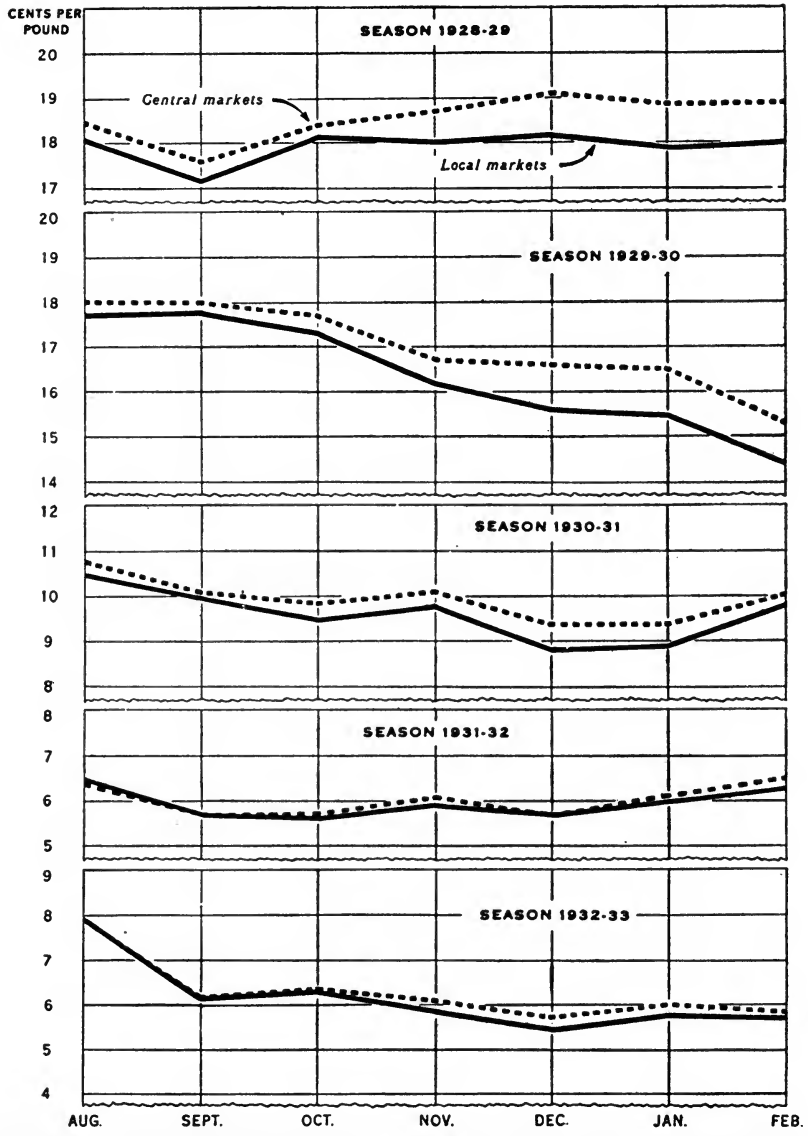

FIGURE 7.—AVERAGE PRICE FOR MIDDLING 7/8-INCH WHITE COTTON IN SELECTED LOCAL MARKETS AND IN CENTRAL MARKETS, BY MONTHS, SEASONS 1928-29 TO 1932-33.

The spreads between the average prices for Middling 7/8-inch White cotton in local markets and those quoted in central markets were relatively narrow from the first of the season up to November. After November the spreads widened as the volume of sales decreased.

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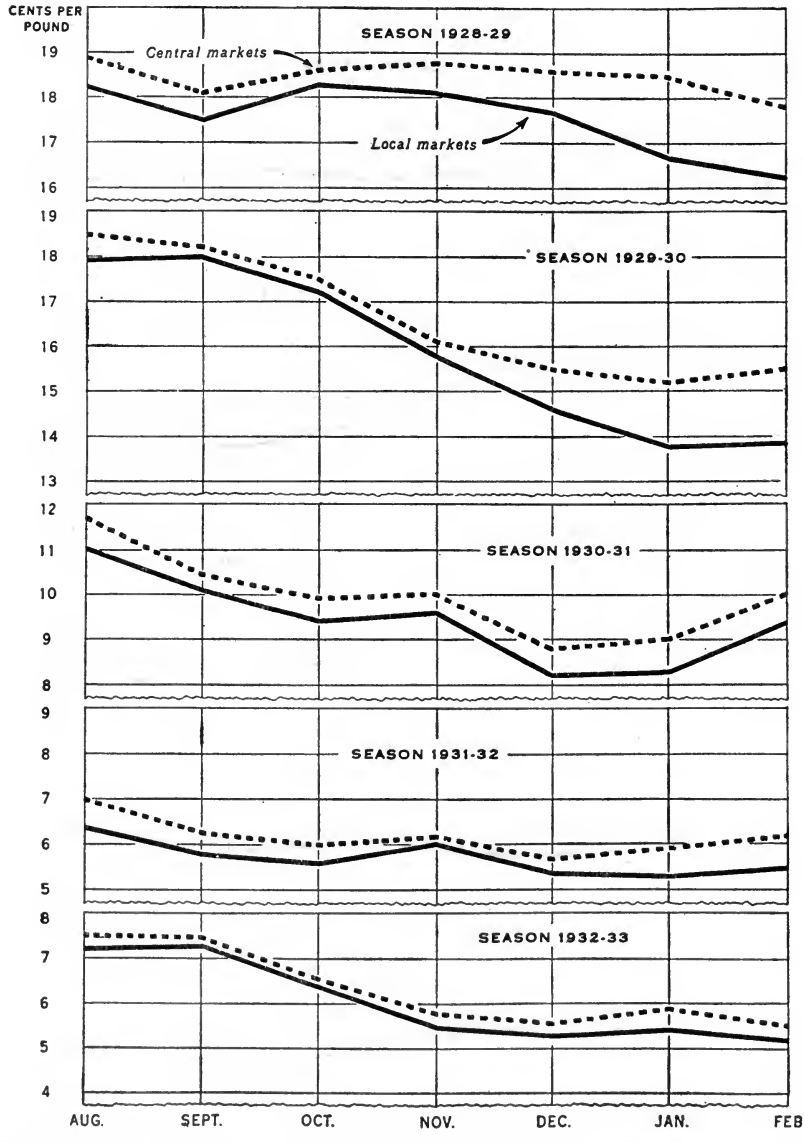

FIGURE 8.—AVERAGE PRICE FOR COTTON OF VARIOUS GRADES AND STAPLE LENGTHS IN SELECTED LOCAL MARKETS AND IN CENTRAL MARKETS, BY MONTHS, SEASONS 1928–29 TO 1932–33.

The spreads between average prices for cotton of various grades and staple lengths in selected local markets and prices quoted in central markets for cotton of the same grade and staple length sold on the same days were for the most part relatively narrow in September, October, and November, when the volume of sales in local markets was relatively large, but they widened as the season advanced and as the volume of sales in local markets decreased.

ROUND LOTS VERSUS INDIVIDUAL-BALE SALES

Cotton sold in round lots in the selected local markets was not even-running in grade and staple length. For example, a round lot sold in a local market in Mississippi on November 1, 1928, consisted of 141 bales, the grades of which ranged from Strict Low Middling to Good Middling, while the staple lengths ranged from 15/16 inch to 1¼ inches and longer. Since the price received for cotton sold in a round lot represents an average for all grades and staple lengths included, such data cannot be used in determining the extent to which prices vary with grade and staple length of individual bales. An analysis of the data collected shows no consistent differences between prices received by growers for cotton sold in round lots and for cotton sold as individual bales. On the whole, however, prices received for cotton sold in round lots averaged somewhat higher than those for cotton of the same grade and staple length sold as individual bales in the same local markets on the same dates. The somewhat higher average prices for cotton sold in round lots than for cotton sold as individual bales may be largely accounted for by the somewhat reduced marketing costs resulting from buying cotton in volume and from the better than average bargaining power of the larger farmers who sell much of their cotton in round lots.

INFLUENCE OF FARM PRICES ON QUALITY OF COTTON PRODUCED

Differences in prices received by growers on the basis of quality may reasonably be expected to influence materially the grade and staple length of the cotton produced, particularly the latter, provided the grower has some knowledge of differences in quality. It is not enough that premiums be paid for higher grades and longer staples and that discounts be made for lower grades and shorter staples in central markets. To be effective, they must be reflected to an appreciable extent in prices received by the grower, the person who finally determines the variety of cotton to be planted. When prices received by growers fail to vary appreciably with the grade and staple length of the cotton sold, growers are naturally more interested in yields than in quality. The grower's apparent indifference to improving the quality of his cotton may be accounted for, partially at least, by the fact that differences in prices received in local markets offer little inducement to the individual grower to attempt such improvement.

Differences in yield obtained also constitute an important factor in determining which variety growers can produce most profitably. In some localities growers are apparently convinced that longer staple varieties out yield the shorter stapled, and are thus more profitable, even when no premiums are paid for longer staples. In other localities, apparently, shorter staple varieties give higher yields, and the costs of production are less than for longer staple varieties, so that the former are more profitable unless the premiums paid for the longer staples counterbalance the differences in yields.

Farmers are generally inclined to grow the kind of cotton which, at prices received in local markets, yields them as individuals the greatest net returns. Although adjustments in cotton production require considerable time and are complicated by seasonal and other factors largely beyond the control of the individual operators, many cotton farmers do respond to economic conditions and do constantly readjust

their productive enterprises in the directions that promise the greatest income (*18*).

The total supply of the different grades and staple lengths of cotton produced by growers who follow their individual economic interests is likely to be out of line with mill demand [11] if prices received by growers fail to reflect accurately the spinning value of the different grades and staple lengths. It is practically impossible, under a system of individual economy, to adjust even fairly accurately the grade and staple length of cotton produced to mill demand unless prices received by growers reflect at least a major part of the differences in spinning value of cotton of different grades and staple lengths.

The prices received in local markets by growers are the media through which the market demand is expressed to them, and these prices, together with information on differences in costs of production, indicate how much and what varieties of cotton they can afford to grow. Relatively high prices received by growers for all cotton tend to result in an increased acreage planted the following year (*37*). Likewise, appreciable premiums received by growers for longer staple cotton offer an inducement for growing longer staple varieties.

Coupled with the failure of prices received by growers to reflect to an appreciable extent premiums and discounts for grade and staple length is the belief on the part of some farmers that the shorter staple varieties give higher yields and that the costs of production are less than for the longer staple varieties. Since very small premiums, on an average, are received in local markets for cotton of longer staples, farmers in some localities are apparently convinced that they can make more money from the production of shorter staple than from the production of longer staple varieties. The proportion of lint to seed cotton is usually greater for shorter staple than for longer staple varieties, and it is possible that growers misjudge the relative yields of varieties because of this difference in the proportion of lint. Total yield per acre of lint cotton is more important than a high gin turn-out, but it is far more difficult to compare yields per acre than it is to compare the proportion of lint to seed cotton.

As a means of pointing out more specifically the relationship between staple length, yield, and comparative value per acre [12] of cotton grown at selected stations, results of cotton variety tests as reported by certain State agricultural experiment stations are shown in table 22. The tabulations are confined to data reported for different stations in Georgia, South Carolina, Alabama, Mississippi, Tennessee, Arkansas, and Louisiana. Results for other stations in these and in other States were not included because completed data for the five seasons included in the study were not available at the time these calculations were made. The stations included are not intended to represent a cross section of cotton-growing conditions in the United States, but are presented merely to show some of the differences in comparative value per acre for cotton of different staple lengths. The data presented for these stations are not complete in that they do not represent cotton of all staple lengths, nor do they indicate the possibilities for improvement of varieties or for the

[11] No accurate measures of mill demand are available. Differences in mill demand are presumably based on difference in spinning utility. Central-market prices are used in this study to represent differences in spinning value or differences in marginal utility, not because they are considered entirely satisfactory measures, but because no better measures were found.

[12] The comparative value per acre represents the value of the lint cotton and cottonseed minus the cost of picking and ginning.

introduction of new varieties at each station. The data presented for each year represent the highest yielding variety of each staple length reported.

These results help to explain why farmers in some localities are not interested in growing longer staple varieties and they emphasize the importance of taking into consideration differences in average yield as well as differences in price received for cotton of different staple lengths in determining the varieties of cotton which can be grown most profitably in each locality. An examination of these data shows that in some localities the differences in yields of the varieties reported are such that longer staple varieties would give a higher comparative value per acre than shorter staple varieties even if no premiums were paid for length of staple. Under such conditions, yields and prices already favor the production of the longer staples. In other localities the differences in yields of the varieties reported are such that shorter staple varieties give a higher comparative value per acre even if full central-market premiums and discounts were reflected in the prices received by growers. Under these conditions, improvements in length of staple are not likely to be made as a result of differences in prices.

Intermediate between these extremes are localities in which differences in yields of the varieties reported are such that when local-market premiums and discounts are applied, shorter staple varieties give the highest comparative value per acre, whereas, when central-market premiums and discounts are applied, longer staple varieties give the highest comparative value per acre. In localities in which these intermediate conditions prevail, differences in premiums and discounts determine the staple length that gives the highest comparative value per acre. The significance of differences in staple premiums and discounts is illustrated by the data for Raymond, Miss., in 1930. By increasing the staple premiums from those received by growers in local markets to those quoted in central markets, the staple length showing the highest comparative value per acre increased from 15/16 inch to 1 1/16 inches on "valley land" and from 13/16 inch to 1 inch on "hill land" (table 22).

In calculating the comparative value per acre, no account was taken of the possible differences in grade resulting from differences in date of maturity and other factors; differences in the strength and uniformity of the fibers; differences in cost per 100 pounds of picking seed cotton; and differences in cost of planting seed. These factors were omitted from the calculations not because they were considered unimportant, but because data available were not adequate for measuring the possible influences of each of these factors. It is realized that the factors not included in the calculations may be of enough importance to increase considerably the differences shown or perhaps in some cases to change the order of relative desirability of different varieties from that indicated by the comparative value per acre.

The failure of prices received by growers to reflect premiums and discounts for grade and staple length equal to those quoted in central markets indicates that the price incentive to growers for the production of different grades and staple lengths was out of line with the spinning value of cotton as reflected by central-market prices. This situation tends to result in the production of larger proportions of the

lower grades and shorter staples than would be the case if production were adjusted more accurately to mill demand as reflected in central-market prices. This lack of adjustment tends to reduce net income to growers as a group and to lower the quality of cotton goods or increase costs to consumers.

MEANS OF ADJUSTING THE QUALITY OF COTTON PRODUCED TO MILL REQUIREMENTS

Needed adjustments in cotton production in the United States can be brought about by improving the marketing system so that a greater proportion of the differences in spinning value of cotton of different grades and staple lengths is reflected in the prices received by growers. Improvements can also be made by giving farmers accurate information regarding the relative profitableness of producing cotton of different qualities in each community and by making readily available at reasonable costs to growers an adequate supply of good planting seed of the varieties of cotton relatively best adapted to conditions in each locality. The opportunities for improving the quality of the cotton produced in many localities in the Cotton Belt by the use of improved varieties that are now available can be materially increased by perfecting the marketing system so as to insure discriminate buying on the basis of quality.

Advice to growers relative to the varieties of cotton which are most profitable in each locality must of necessity be based on differences in prices actually received by growers for cotton of the various grades and staple lengths, along with the differences in cost of production. Profits to individual growers in some localities can be increased by producing longer staple cotton, even under present marketing conditions. The best information available indicates that not all farmers in each locality are producing cotton of staple lengths best adapted to their condition at the present time. Some farmers grow shorter staple varieties in localities where longer staple varieties would be evidently more profitable, and vice versa. These maladjustments may be due in part to the farmers' lack of reliable information relative to the varieties of cotton best adapted to conditions in each locality and to difficulties in obtaining good seed of the best varieties.

Conditions in local markets can be improved by:

(*1*) *Classification of cotton before it is sold by growers.*—In order that farmers might sell their cotton in local markets strictly on a quality basis, under the present marketing system, it would be necessary that both growers and local buyers know the quality and commercial value of the cotton at the time of making the transaction. Since farmers and many local cotton buyers are not able to classify cotton accurately, a means of improvement would be to have disinterested, competent, and reliable persons classify the cotton according to a uniform standard and issue a certificate showing the grade, staple length, and character of each bale before it is sold. This classification and certification of cotton while it is in the possession of the grower would increase the bargaining power of farmers who produce the higher qualities of cotton, increase the usefulness of price quotations for grade and staple length, reduce the waste from resampling, improve the use of cotton-warehouse receipts as collateral

for loans, and result in other economies in cotton marketing. Difficulties such as assembling the cotton in sufficient volume and providing adequate facilities for classing the cotton accurately and economically, securing competent classers and providing for their supervision, developing standards for character, and other problems would be encountered. Although considerable time and effort would be required to overcome these difficulties, they are not considered insurmountable.

(*2*) *Producing cotton of more uniform quality in each community.*—Discriminate buying in local markets on the basis of quality can be facilitated by producing cotton of more uniform quality in each community so that the volume of cotton of each grade and staple length produced in each community will be large enough to be handled more economically. This is being accomplished at the present time in some communities by the standardization of varieties and by reducing the number of varieties grown. Increased profits can be obtained in many communities by standardizing the production of longer staple varieties.

(*3*) *Supplying farmers with adequate information on cotton prices.*—Farmers in each community need information on cotton prices in central markets and in nearby points of concentration, including prices for Middling ⅞-inch cotton and premiums and discounts for the various other grades and staple lengths. With this information and a knowledge of the quality of the cotton before it is sold, farmers who produce the higher qualities will be in a better position to bargain more effectively with buyers.

SUMMARY AND CONCLUSIONS

Cotton prices in local markets in the United States do not accurately reflect differences in the spinning value of the various grades and staple lengths. Prices in local markets varied so irregularly on the basis of grade and staple length during the seasons 1928–29 to 1932–33 that it was not unusual for some farmers to receive considerably higher prices for some grades and staples than other farmers received for higher grades and longer staples sold in the same markets on the same days.

Average prices in local markets were somewhat higher for the higher grades and longer staples than for the lower grades and shorter staples, but the average premiums paid for the higher grades and longer staples and the average discounts made for the lower grades and shorter staples were considerably less than those quoted in central markets. The proportion of central-market premiums reflected in local-market prices amounted to about 33 percent for the grades above Middling and to only about 17 percent for staples longer than ⅞ inch. The proportions of central-market discounts made to growers amounted to 60 percent for grades below Middling and to less than 6 percent for staples shorter than ⅞ inch.

Average premiums and discounts in local markets were considerably less in many cases than the differences in prices received for cotton of the same grade and staple-length designations sold in the same local markets on the same days.

Average premiums for the higher grades and longer staples and average discounts for the lower grades and shorter staples in local markets varied irregularly from month to month. No consistent

differences were found between average premiums for higher grades and longer staples and average discounts for lower grades and shorter staples in local markets of different types. No consistent relationships were found between the number of buyers or the type of buyers and the average premiums and discounts for grade and staple length in local markets.

Lack of knowledge of the correct classification and of the commercial value of the cotton, differences in the character of cotton, inadequate volume of some of the grades and staple lengths, and differences in bargaining power of farmers and of local buyers are considered the principal factors responsible for the failure of local market prices to reflect a larger proportion of central-market premiums and discounts for grade and staple length.

Although local-market prices paid for individual bales did not vary consistently with the grade and staple length of the cotton, average prices were generally somewhat higher in selected local markets where the cotton sold averaged higher in grade and longer in staple than in those in which the cotton sold averaged lower in grade and shorter in staple. These differences in average prices were great enough in many cases to equal the premiums and discounts for grade and staple length quoted in central markets for the cotton included in the study.

The failure of local-market prices to reflect a larger proportion of central-market premiums and discounts for different grades and staple lengths makes it impossible for growers who could otherwise afford to produce the higher grades and longer staples to realize the full benefits of their favorable positions. It results in the production of larger proportions of the lower grades and shorter staples than would be the case if production were better adjusted to mill demand as reflected in central-market prices. Such conditions tend to reduce net income to growers as a group and to lower the quality of the cotton goods or increase the costs to consumers.

Needed adjustments in cotton production in the United States can be brought about (1) by improving the marketing system so that a greater proportion of the differences in spinning value of cotton of different grades and staple lengths will be reflected in the prices received by growers, (2) by giving farmers accurate information regarding the varieties of cotton relatively best adapted to conditions in each locality, and (3) by making readily available at reasonable costs to growers an adequate supply of good planting seed of the varieties of cotton relatively best adapted to conditions in each locality.

The present local-marketing practices can be improved (1) by having disinterested, competent, and reliable persons classify the cotton according to a uniform standard and issue a certificate showing the grade, staple length, and character of each bale before it is sold by the grower; (2) by encouraging the production of cotton of more uniform quality in each community so that the volume of cotton of each grade and staple length produced in each community will be large enough to be handled more economically; and (3) by supplying farmers with more adequate information on cotton prices in central markets and in nearby points of concentration, including prices for Middling ⅞-inch cotton and premiums and discounts for the various other grades and staple lengths.

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APPENDIX

METHOD OF ANALYZING LOCAL-MARKET PRICES

CALCULATION OF LOCAL MARKET PREMIUMS AND DISCOUNTS

The average local-market premiums and discounts for grade and staple were obtained from spreads between prices received by growers in local markets and those quoted in central markets for cotton of the same grade and staple length sold on the same dates. Averages of actual prices received by growers were not used in calculating premiums and discounts for grade and staple length. This was in part because of the enormous number of tabulations required to calculate differences on the basis of daily average prices, and also because monthly or seasonal averages of actual prices might be influenced enough by price fluctuations, along with variations in the grade and staple length of the cotton, to indicate that higher average prices were received by growers for cotton of lower grade and shorter staple length than for cotton of higher grade and longer staple length. This might occur even if prices received by growers from day to day varied appreciably with the grade and staple length of the cotton.

It is believed that premiums and discounts for grade and staple length calculated from the average spreads between local- and central-market prices, as in this study, do not differ appreciably from those that would have been obtained on the basis of daily average prices. This belief is supported by the fact that the average premiums and discounts for grade and staple length in 11 selected local markets in Alabama in 1928–29, and in 13 selected local markets included in the study each year from 1929–30 to 1932–33, when calculated on the basis of average spreads, generally did not differ by amounts as great as the standard error of the mean from those calculated from the same data on the basis of daily average prices.

To obtain a figure representing the spread between local- and central-market prices, the price received by the grower was subtracted from an average of the prices quoted in central markets for cotton of the same grade and staple length sold on the same day. Variations in spread resulting from fluctuations in prices in local markets during the day were not eliminated. It is believed that variations in spread for cotton of different grades and staple lengths resulting from fluctuations in prices during the day tend to compensate each other when averaged, since there appears no good reason for assuming that any one grade or staple length is more likely to be sold than any other during the period of the day when the prices are relatively high or relatively low. Fluctuations in prices during the day, however, may account for a considerable portion of the irregular variations in prices received by growers for cotton of different grades and staple lengths sold in the same local markets on the same date.

An average spread was calculated for cotton of each grade and staple length marketed each month in each local market. The monthly average spread for ⅞-inch cotton of each grade in each local market was subtracted from the monthly average spread for each staple length of the same grade in the same market to give monthly average adjusted spreads for cotton of different staple lengths. For example, if the average spread for Middling ⅞-inch White cotton was 0.15 cent a pound and the average spread for Middling $1\frac{5}{16}$-inch White cotton sold in the same market during the same month was 0.45 cent a pound, the average adjusted spread for Middling ⅞-inch White cotton would be 0 and for Middling $1\frac{5}{16}$-inch White cotton would be 0.30 cent a pound. Similarly, the monthly average spread for Middling White cotton of each staple length was subtracted from the monthly average spread for each grade of the same staple length to give monthly average adjusted spreads for cotton of different grades. These spreads were adjusted for each market each month on the basis of Middling White grade and of ⅞-inch staple length, in an attempt to eliminate from consideration differences in price level in the same market, from month to month, as well as differences in different markets, and also to make possible the combination of the adjusted spreads for cotton of the same grade and staple length sold during different months and in different markets.

It is realized that such adjustment of spreads does not eliminate completely the influence of month-to-month fluctuations in prices in local markets along with changes in the grade and staple length of the cotton sold when local market price fluctuations do not move parallel with those in central markets. If the price changes in local markets were always made at the same time, in the same amounts, and in the same direction, as those quoted in central markets, monthly adjustments would be unnecessary. When the spread between local and central-

market prices increases as the season advances, along with decreases in the grade and staple length of the cotton sold, average premiums and discounts for grade and staple length, calculated from the spread, and not adjusted monthly, show differentials somewhat greater than actually prevailed in the markets. Irregular variations in spread with grade and staple length result in errors that are compensating in nature and are thought not to affect materially the average result when the sample is large, as was the case in this study. The spread between local- and central-market prices increased somewhat as the season advanced during each of the 5 years included in the study, and these increases were accompanied by some decreases in average grade and staple length of the cotton sold. That the influence of these fluctuations in spread from one part of the season to another, along with changes in average grade and staple length of the cotton sold, was largely eliminated by making monthly adjustments is evidenced by the fact that premiums and discounts for grade and staple lengths in selected local markets in South Carolina in 1929–30, when calculated from spreads adjusted weekly, did not differ appreciably from those for the same data calculated from spreads adjusted monthly.

An adjusted average spread for cotton of each grade and staple length in each local market for the season was obtained by taking an average of the monthly adjusted spreads calculated as indicated above. An adjusted average spread for cotton of each grade and staple length for the United States was obtained by taking an average of the adjusted spreads in all selected local markets.

The adjusted spread for the different grades and staple lengths shows the extent to which the premiums and discounts for grade and staple length in local markets varied from those quoted in central markets. The adjusted spread of 0.30 cent a pound for Middling 15/16-inch White cotton obtained as indicated above means that staple premiums received by growers averaged 0.30 cent a pound less than the average premium quoted in central markets. The actual premiums and discounts for grade and staple length in local markets were obtained by subtracting these adjusted spreads from the premiums and discounts for grade and staple length quoted in central markets. For example, if the central-market staple premiums for Middling 15/16-inch White cotton amounted to 0.35 cent a pound, then by subtracting the adjusted spread of 0.30 cent a pound, referred to above, from the central-market premium, 0.05 cent a pound is obtained which represents the average staple premium for Middling 15/16-inch White cotton actually received by growers.

CALCULATION OF FREQUENCY DISTRIBUTIONS

Frequency distributions of the variations in prices received by growers were calculated for the purpose of determining the extent of variations in prices received by growers for cotton of the same grade and staple length sold in the same local markets, with the influence of differences in date of sale largely eliminated. In arriving at frequency distributions of the variations in prices received by growers for cotton of different grades and staple lengths, frequency distributions of the spreads were calculated for Middling White cotton of each staple length, and for 7/8-inch White cotton of each grade sold each month in each local market. These monthly frequency distributions of spreads were then adjusted by subtracting the monthly average spread for Middling 7/8-inch White cotton from the class intervals of the frequency distributions of the spread for each staple length of Middling White cotton, and for each grade of 7/8-inch White cotton. The frequency distributions of the spreads for each market for each month were adjusted on the basis of Middling White grade and of 7/8-inch staple length. This was an attempt to eliminate from consideration differences in price level in the same market, from month to month, and also in different markets, and to make it possible to combine the adjusted frequencies of the spreads for cotton of the same grade and staple length sold during different months and in different markets. An adjusted frequency distribution of the variations in spread for cotton of each grade and staple length for the United States was obtained by combining the adjusted frequency distributions of spread for all months and for all local markets studied.

These adjusted-frequency distributions of spread for cotton of different grades and staple lengths show the extent to which the premiums and discounts for grade and staple length in local markets varied from those quoted in central markets. Frequency distributions of the actual premiums and discounts for grade and staple length in local markets were obtained by subtracting the class intervals of the frequency distributions of spread from the average premiums and discounts for grade and staple length quoted in central markets.

RELATION OF AVERAGE PRICES TO AVERAGE QUALITY IN DIFFERENT MARKETS

The extent to which average prices received by growers in different local markets reflected the average quality of the cotton sold, as indicated by grade and staple length, was determined as follows:

Average prices received by growers for cotton of various grades and staple lengths sold in the different local markets were adjusted for differences in location by adding to the prices at selected local markets in Texas and Oklahoma the costs of compression and freight to Houston, Tex., and to prices at selected local markets in Arkansas, Louisiana, Mississippi, and Tennessee the cost of compression and freight to New Orleans. These adjustments were based on the assumption that prices in local markets tend to equal central-market prices, minus carrying charges from the local to the central markets. Interest, risk, insurance, and other costs enter into carrying charges, but the differences in these costs were so small that they had little influence on the differences in price level. It was recognized that concentration privileges, savings from through bills of lading, and other factors, may result in prices in local markets which differ considerably from central-market prices, minus costs of compressing and freight from the local to the central market but adequate data were not available for making adjustments for these factors.

Railroad rates were used in making adjustments for differences in transportation costs. It is realized that in some years cotton was shipped by truck from some of the markets included in the study, and it is not known to what extent the truck rates differed from rail rates. Furthermore, part of the cotton from Mississippi, Arkansas, Louisiana, Tennessee, and eastern Texas and Oklahoma moved directly overland to eastern mills, but the data available are not adequate for making satisfactory adjustments in local-market prices for differences in cost of transportation to domestic mills. No adjustments were made in local-market prices in the mill sections of North Carolina, South Carolina, Georgia, and Alabama for differences in transportation costs to central markets.

The problem of making adjustments for differences in the location of the selected local markets in the Southeastern States was complicated by the fact that some localities included in the study had some of the characteristics of both a deficit- and a surplus-producing territory. Mills in some localities of North Carolina, South Carolina, Georgia, and Alabama consumed more of certain grades and staple lengths than were produced in the immediate territory, whereas other grades and staple lengths not suitable for local mill consumption had to be exported or shipped to other mills. Data available are not adequate for determining to what extent prices in each of the selected local markets in these States were determined upon the basis of export prices.

Prices of Middling ⅞-inch cotton in central markets were subtracted from these adjusted local-market prices to give a spread between local- and central-market prices. The average of these spreads for all local markets combined was subtracted from the average spread for each local market to give variations in average adjusted spreads from market to market. Central-market premiums and discounts for grade and staple length were applied to the cotton sold in each local market and included in the sample, and the averages were calculated to show the number of cents a pound the cotton in each local market averaged "on" or "off" the prices of Middling ⅞-inch cotton. The average number of cents a pound "on" or "off" Middling ⅞-inch for all local markets combined was subtracted from the average number of cents a pound "on" or "off" Middling ⅞ inch for each local market to give average adjusted variations in central-market evaluations from market to market. The variations in average adjusted spreads were related to variations in average adjusted central-market evaluations to show the extent to which average prices received by growers in different local markets reflected differences in the average quality of the cotton sold.

CALCULATION OF MONTHLY AVERAGE PRICES

In calculating monthly average prices in all local markets combined, the influences of differences in price level in different local markets, together with monthly changes in the proportion of the total sample coming from different local markets, were eliminated by the following procedure:

The average spread for the season for each selected local market was obtained by subtracting the prices received by growers from those quoted in central markets for cotton of the same grade and staple length sold on the same dates. These average spreads for the season were subtracted from the average spreads for each month, to give monthly variations in spread from the seasonal average.

The monthly variations in spread for the different local markets were combined to give monthly average variations in spread for all local markets included in the sample. The average spread for the season for cotton sold in all local markets was added to the average monthly variations in spread for all local markets to obtain the monthly average adjusted spread for all local markets combined. The average monthly local market prices were obtained by subtracting the monthly average adjusted spreads from the monthly central-market prices.

Monthly central-market prices were obtained by weighting the daily quotations by the number of bales of cotton of the same description sold on the same day and included in the sample of cotton sold in the selected local markets. In obtaining average central-market prices for cotton of various grades and staple lengths, premiums and discounts for grades of ⅞-inch staple were applied to other staple lengths, and staple premiums and discounts for Middling grade were applied to other grades. The prices obtained in this way are obviously only rough approximations, and their accuracy depends upon the extent to which the greater staple premiums and discounts for the higher grades are counterbalanced by the smaller staple premiums and discounts for the lower grades.

CALCULATION OF COMPARATIVE VALUE PER ACRE

The comparative values per acre for cotton of different staple lengths were obtained by subtracting from the value of the lint cotton and cottonseed the costs of picking, ginning, and bagging and ties. Data on average staple length, yield per acre, and percentage of lint to seed, were obtained from reports of the State agricultural experiment stations. The value of the cottonseed was based on the average seasonal price received by growers as reported by the Bureau of Agricultural Economics. The prevailing rates for picking, ginning, and bagging and ties, were used in calculating the cost. The average price received by growers in local markets for Middling ⅞-inch White cotton was used as a basis, and to this basis were applied local-and central-market staple premiums and discounts.

TABLES

TABLE 17.—*Price per pound received by growers for White cotton of various grades and staple lengths sold in selected local markets on specified dates, season 1929–30* [1]

MARKET C, 4 BUYERS OF DIFFERENT TYPES, OCT. 12, 1929 [2]

Grade	Shorter than ⅞ inch		⅞ inch		15/16 inch		1 inch		1 1/16 inches		1 1/8 inches	
	Sales	Price	Sales	Price	Sales	Price	Sales	Price	Sales	Price	Sales	Price
	Bales	*Cents*	*Bales*	*Cents*	*Bales*	*Cents*	*Bales*	*Cents*	*Bales*	*Cents*	*Bales*	*Cents*
4, Strict Middling	------	------	1	17.75	1	18.25	------	------	1	18.65	------	------
	------	------	1	18.55	1	18.60	------	------	------	------	------	------
	------	------	4	18.60	1	18.62	------	------	------	------	------	------
	------	------	1	18.63	2	18.65	------	------	------	------	------	------
	------	------	4	18.65	3	18.75	------	------	------	------	------	------
	------	------	1	18.67	1	18.80	------	------	------	------	------	------
	------	------	1	18.70	1	18.85	------	------	------	------	------	------
	------	------	1	18.75	1	18.90	------	------	------	------	------	------
	------	------	1	18.85	------	------	------	------	------	------	------	------
5, Middling	------	------	1	18.25	1	18.55	------	------	------	------	------	------
	------	------	1	18.50	1	18.62	------	------	------	------	------	------
	------	------	1	18.60	------	------	------	------	------	------	------	------
	------	------	2	18.63	------	------	------	------	------	------	------	------
	------	------	1	18.65	------	------	------	------	------	------	------	------
	------	------	5	18.75	------	------	------	------	------	------	------	------
	------	------	1	18.85	------	------	------	------	------	------	------	------
6, Strict Low Middling	------	------	1	18.10	1	17.00	------	------	------	------	------	------
	------	------	1	18.80	------	------	------	------	------	------	------	------

MARKET D, 9 BUYERS OF DIFFERENT TYPES, OCT. 10, 1929 [3]

4, Strict Middling	------	------	------	------	1	18.60	1	17.75	1	19.25	1	19.25
	------	------	------	------	------	------	1	18.00	1	19.37	------	------
	------	------	------	------	------	------	1	18.50	------	------	------	------
5, Middling	------	------	2	18.00	1	18.40	1	18.00	3	19.00	------	------
	------	------	1	18.55	1	18.50	1	18.35	------	------	------	------
	------	------	1	18.60	2	18.60	1	19.00	------	------	------	------
	------	------	1	18.75	------	------	------	------	------	------	------	------

See footnotes at end of table.

TABLE 17.—*Price per pound received by growers for White cotton of various grades and staple lengths sold in selected local markets on specifie dates, season 1929–30*—Continued

MARKET E, 3 BUYERS OF DIFFERENT TYPES, OCT. 26, 1929 [4]

Grade	Shorter than 7/8 inch		7/8 inch		15/16 inch		1 inch		1 1/16 inches		1 1/8 inches	
	Sales	Price	Sales	Price	Sales	Price	Sales	Price	Sales	Price	Sales	Price
	Bales	*Cents*	*Bales*	*Cents*	*Bales*	*Cents*	*Bales*	*Cents*	*Bales*	*Cents*	*Bales*	*Cents*
5, Middling			4	16.50	2	16.50						
6, Strict Low Middling	1	16.50	6	16.50	1	16.50						
7, Low Middling	2	16.50	3	16.50	1	16.50						

[1] No round lot sales are included.
[2] The price of New York futures contracts did not vary on this date because it was a holiday.
[3] The price of New York futures contracts for December delivery varied 12 points on this date.
[4] The price of New York futures contracts for December delivery varied 9 points on this date.

TABLE 18.—*Price per pound received by growers for White cotton of various grades and staple lengths sold in selected local markets on specified dates, season 1930–31* [1]

MARKET F, 5 BUYERS, SEPT. 19, 1930 [2]

Grade	Shorter than 7/8 inch		7/8 inch		15/16 inch	
	Sales	Price	Sales	Price	Sales	Price
	Bales	*Cents*	*Bales*	*Cents*	*Bales*	*Cents*
4, Strict Middling			1	10.00		
5, Middling	1	9.75	1	9.25		
			1	9.50		
			1	9.88		
			1	10.00		
			1	11.00		
6, Strict Low Middling			1	9.75	1	9.25
			1	9.81		
7, Low Middling					1	9.49

MARKET G, 2 BUYERS, SEPT. 26, 1930 [3]

4, Strict Middling			1	8.50	1	9.00
			1	9.00		
5, Middling	1	8.50	2	9.00		
			1	9.25		
			3	9.63		
6, Strict Low Middling	2	8.50	1	8.25	1	8.38
	1	8.63	1	8.38	1	8.75
	2	8.75	1	8.44		
	3	8.81	1	8.50		
	1	9.00	1	8.56		
	1	9.06	3	8.63		
	1	9.50	1	8.69		
			3	8.75		
			5	8.81		
			1	8.88		
			2	9.00		
			1	9.31		
7, Low Middling	1	8.75	1	8.38		
			2	8.50		
	1	8.81	1	8.63		
	1	9.25	1	8.75		

MARKET H, 1 BUYER, OCT. 10, 1930 [4]

3, Good Middling			1	8.40		
			1	9.00		
4, Strict Middling	3	8.40	3	8.40	1	9.25
	1	9.00	1	8.50	1	9.50
	1	8.50	1	8.25	1	8.40
5, Middling			4	8.40	1	8.50
			1	9.25		
			2	9.37		

[1] No round-lot sales are included.
[2] The price of New York futures contracts for December delivery varied 12 points on this date.
[3] The price of New York futures contracts for December delivery varied 13 points on this date.
[4] The price of New York futures contracts for December delivery varied 25 points on this date.

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TABLE 19.—*Price per pound received by growers for White cotton of various grades and staple lengths sold in selected local markets on specified dates, seasons 1931–32 and 1932–33* [1]

MARKET I, 1 BUYER, WHO OPERATED A STORE, OCT. 2, 1931 [2]

Grade	⅞ inch		15/16 inch		1 inch		1 1/16 inches		1 1/8 inches	
	Sales	Price	Sales	Price	Sales	Price	Sales	Price	Sales	Price
	Bales	*Cents*	*Bales*	*Cents*	*Bales*	*Cents*	*Bales*	*Cents*	*Bales*	*Cents*
4, Strict Middling	1	5.50	-------	-------	1	5.75	4	6.25	-------	-------
	-------	-------	-------	-------	7	6.25	-------	-------	-------	-------
5, Middling	3	5.50	3	5.50	1	5.50	-------	-------	-------	-------
	1	5.60	2	5.75	1	6.00	-------	-------	-------	-------
	6	5.75	1	6.25	4	6.25	-------	-------	-------	-------
6, Strict Low Middling	1	5.75	-------	-------	1	5.75	-------	-------	-------	-------

MARKET J, 1 BUYER, WHO OPERATED A STORE, SEPT. 23, 1932 [3]

4, Strict Middling	2	7.25	-------	-------	-------	-------	-------	-------	-------	-------
	4	7.50	-------	-------	-------	-------	-------	-------	-------	-------
5, Middling	3	7.25	1	7.25	1	6.75	1	6.00	1	7.75
	1	7.50	1	7.75	2	7.25	1	7.00	1	8.00
	1	7.75	-------	-------	1	7.75	1	7.75	-------	-------
6, Strict Low Middling	-------	-------	-------	-------	-------	-------	1	7.75	-------	-------

[1] No round-lot sales are included.
[2] The price of New York futures contracts for December delivery varied 14 points on this date.
[3] The price of New York futures contracts for December delivery varied 21 points on this date.

TABLE 20.—*Frequency distribution of variations in prices* [1] *per pound received by growers for individual bales of specified grades of White* [2] *cotton of ⅞-inch staple from the average price received for Middling White cotton of the same staple length in selected local markets, seasons 1928–29 to 1932–33*

SEASON 1928–29

Variation (cents)	2, Strict Good Middling	3, Good Middling	4, Strict Middling	5, Middling	6, Strict Low Middling	7, Low Middling	8, Strict Good Ordinary	9, Good Ordinary
	Bales	*Bales*	*Bales*	*Bales*	*Bales*	*Bales*	*Bales*	*Bales*
−5.60 to −5.21	-------	-------	-------	-------	-------	-------	-------	1
−5.20 to −4.81	-------	-------	-------	1	-------	-------	1	-------
−4.80 to −4.41	-------	-------	-------	-------	1	2	5	5
−4.40 to −4.01	-------	-------	-------	-------	1	4	6	12
−4.00 to −3.61	-------	1	-------	-------	3	10	16	25
−3.60 to −3.21	-------	-------	1	1	5	19	11	22
−3.20 to −2.81	-------	-------	2	1	16	34	43	19
−2.80 to −2.41	-------	-------	5	2	36	55	40	21
−2.40 to −2.01	-------	3	7	10	50	51	38	18
−2.00 to −1.61	-------	4	19	27	98	100	60	13
−1.60 to −1.21	-------	6	51	90	220	164	42	9
−1.20 to −0.81	-------	38	290	342	513	220	54	9
−0.80 to −0.41	1	212	1,148	1,293	923	267	49	7
−0.40 to −0.01	14	791	4,143	3,748	1,146	202	36	4
0.00 to 0.39	24	1,257	5,640	4,171	896	129	15	3
0.40 to 0.79	4	517	2,317	1,347	377	43	7	-------
0.80 to 1.19	2	144	568	251	75	12	1	-------
1.20 to 1.59	-------	80	186	62	17	4	1	-------
1.60 to 1.99	1	99	75	18	5	1	-------	-------
2.00 to 2.39	-------	27	38	6	1	-------	-------	-------
2.40 and over	-------	1	8	7	12	2	-------	-------
Total	46	3,180	14,498	11,377	4,395	1,319	425	168
	Cents	*Cents*	*Cents*	*Cents*	*Cents*	*Cents*	*Cents*	*Cents*
Mean	0.14	0.21	0.12	0.00	−0.34	−0.94	−1.68	−2.66
Standard error of mean	.06	.01	.00	.00	.01	.03	.06	.09
Average deviation	.26	.38	.36	.36	.54	.75	.97	.96
Approximate range [3]	2.40	7.20	6.00	8.40	9.60	8.00	6.40	5.60

See footnotes at end of table.

TABLE 20.—*Frequency distribution of variations in prices [1] per pound received by growers for individual bales of specified grades of White [2] cotton of ⅞-inch staple from the average price received for Middling White cotton of the same staple length in selected local markets, seasons 1928–29 to 1932–33*—Continued

SEASON 1929–30

Variation (cents)	2, Strict Good Middling	3, Good Middling	4, Strict Middling	5, Middling	6, Strict Low Middling	7, Low Middling	8, Strict Good Ordinary	9, Good Ordinary
	Bales	*Bales*	*Bales*	*Bales*	*Bales*	*Bales*	*Bales*	*Bales*
Under −6.00					2	3	7	1
−6.00 to −5.61						5	9	1
−5.60 to −5.21					1	16	37	8
−5.20 to −4.81					2	18	23	8
−4.80 to −4.41				1	8	34	27	6
−4.40 to −4.01			2	2	7	33	26	1
−4.00 to −3.61				2	12	35	18	5
−3.60 to −3.21			1	5	20	85	41	10
−3.20 to −2.81			3	5	26	110	54	26
−2.80 to −2.41			1	7	62	149	66	17
−2.40 to −2.01		1	2	24	108	178	67	8
−2.00 to −1.61			12	30	183	219	47	2
−1.60 to −1.21		2	32	107	297	246	59	1
−1.20 to −0.81		16	113	340	603	254	43	3
−0.80 to −0.41	1	107	779	1,347	1,033	268	43	4
−0.40 to −0.01	3	535	3,768	4,937	1,770	246	22	15
0.00 to 0.39	13	726	5,231	5,586	1,162	171	14	14
0.40 to 0.79	4	318	1,813	1,464	386	53	4	1
0.80 to 1.19	1	61	403	310	117	19		1
1.20 to 1.59		9	72	72	33	7	1	
1.60 to 1.99		5	22	12	10	4	2	
2.00 to 2.39			14	6	2	2	4	
2.40 and over		2	9	7	5			
Total	22	1,782	12,277	14,264	5,849	2,155	614	132
	Cents	*Cents*	*Cents*	*Cents*	*Cents*	*Cents*	*Cents*	*Cents*
Mean	0.21	0.14	0.11	0.00	−0.40	−1.46	−2.54	−2.48
Standard error of mean	.07	.01	.00	.00	.01	.03	.07	.16
Average deviation	.20	.32	.31	.34	.58	1.07	1.33	1.45
Approximate range [3]	1.60	5.60	7.60	8.00	11.20	8.80	9.60	7.60

SEASON 1930–31

	Bales	*Bales*	*Bales*	*Bales*	*Bales*	*Bales*	*Bales*	*Bales*
Under −6.00						1		
−6.00 to −5.61								
−5.60 to −5.21								1
−5.20 to −4.81								
−4.80 to −4.41						3		1
−4.40 to −4.01					2	1	1	1
−4.00 to −3.61					2	4	5	2
−3.60 to −3.21					3	7	8	
−3.20 to −2.81			2	1	8	15	12	1
−2.80 to −2.41			3	3	11	33	21	1
−2.40 to −2.01		1	3	5	33	102	29	1
−2.00 to −1.61		1	18	15	84	184	49	4
−1.60 to −1.21		7	43	41	185	188	33	5
−1.20 to −0.81		27	123	176	512	289	29	4
−0.80 to −0.41		162	681	922	1,013	329	17	1
−0.40 to −0.01	13	605	2,927	3,633	1,486	230	13	3
0.00 to 0.39	12	606	3,662	4,403	1,098	132	6	
0.40 to 0.79	5	261	1,034	842	270	25	4	2
0.80 to 1.19	1	62	211	149	44	5	1	
1.20 to 1.59	1	23	52	21	6	1	1	
1.60 to 1.99		6	12	3	6	2		
2.00 to 2.39			4		1			
2.40 and over			3		2	1	1	
Total	32	1,761	8,778	10,214	4,766	1,552	230	27
	Cents	*Cents*	*Cents*	*Cents*	*Cents*	*Cents*	*Cents*	*Cents*
Mean	0.17	0.07	0.05	0.00	−0.32	−0.96	−1.61	−1.77
Standard error of mean	.07	.01	.00	.00	.01	.02	.07	.29
Average deviation	.29	.36	.32	.31	.46	.65	.79	1.15
Approximate range [3]	1.60	4.00	7.20	4.80	6.80	9.60	7.60	6.00

See footnotes at end of table.

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TABLE 20.—*Frequency distribution of variations in prices* [1] *per pound received by growers for individual bales of specified grades of White* [2] *cotton of 7/8-inch staple from the average price received for Middling White cotton of the same staple length in selected local markets, seasons 1928–29 to 1932–33*—Continued

SEASON 1931–32

Variation (cents)	2, Strict Good Middling	3, Good Middling	4, Strict Middling	5, Middling	6, Strict Low Middling	7, Low Middling	8, Strict Good Ordinary	9, Good Ordinary
	Bales	*Bales*	*Bales*	*Bales*	*Bales*	*Bales*	*Bales*	*Bales*
−2.40 to −2.01			1					
−2.00 to −1.61								
−1.60 to −1.21				2	2	1	16	9
−1.20 to −0.81			15	8	10	7	24	27
−0.80 to −0.41		16	153	145	108	42	21	6
−0.40 to −0.01		170	1,294	1,275	492	101	26	5
0.00 to 0.39		244	1,451	1,367	411	64	21	1
0.40 to 0.79		64	228	98	43	12	3	
0.80 to 1.19		5	25	17	2			
1.20 to 1.59		1	3	1				
1.60 to 1.99								
Total		500	3,170	2,913	1,068	227	111	48
	Cents	*Cents*	*Cents*	*Cents*	*Cents*	*Cents*	*Cents*	*Cents*
Mean		0.10	0.03	0.00	−0.06	−0.15	−0.52	−0.92
Standard error of mean		.01	.00	.00	.01	.02	.05	.05
Average deviation		.25	.26	.24	.26	.28	.49	.27
Approximate range [3]		2.00	3.60	2.80	2.40	2.00	2.00	1.60

SEASON 1932–33

	Bales	*Bales*	*Bales*	*Bales*	*Bales*	*Bales*	*Bales*	*Bales*
−2.80 to −2.41				1				
−2.40 to −2.01		1						
−2.00 to −1.61		1			1			
−1.60 to −1.21			5	1	1	2		
−1.20 to −0.81		5	20	17	13	13	9	3
−0.80 to −0.41		26	180	208	137	43	16	5
−0.40 to −0.01		138	1,236	1,961	685	100	10	1
0.00 to 0.39		63	1,305	1,919	516	89	8	1
0.40 to 0.79		12	200	205	49	1	1	
0.80 to 1.19		2	11	17	3	1		
1.20 to 1.59			3	4	1			
1.60 to 1.99				1				
2.00 to 2.39			1					
2.40 to 2.79				1				
2.80 to 3.19				1				
Total		248	2,961	4,336	1,406	247	46	10
	Cents	*Cents*	*Cents*	*Cents*	*Cents*	*Cents*	*Cents*	*Cents*
Mean		0.13	0.01	0.00	−0.07	−0.16	−0.47	−0.62
Standard error of mean		.02	.01	.00	.01	.02	.07	.12
Average deviation		.35	.26	.25	.25	.27	.39	.25
Approximate range [3]		3.20	3.60	5.60	3.20	2.00	2.00	1.20

[1] Minus sign (−) means below the average price for Middling White cotton.
[2] Extra White cotton included.
[3] The approximate range was measured from the mid-point of the extreme classes.

TABLE 21.—*Frequency distribution of variations in prices [1] per pound received by growers for individual bales of specified staple lengths of Middling White [2] cotton from the average price received for ⅞-inch cotton of the same grade in selected local markets, seasons 1928–29 to 1932–33*

SEASON 1928–29

Variation (cents)	Shorter than ⅞ inch	⅞ inch	15/16 inch	1 inch	1 1/16 inches	1 ⅛ inches	1 3/16 inches	1 ¼ inches and longer
	Bales	*Bales*	*Bales*	*Bales*	*Bales*	*Bales*	*Bales*	*Bales*
Under −2.80	4	3	3					
−2.80 to −2.41	7	2	4	1	2			
−2.40 to −2.01	19	10	18	6	1			
−2.00 to −1.61	13	27	33	11	7	3		
−1.60 to −1.21	36	90	78	39	15	2		
−1.20 to −0.81	99	342	292	126	41	9	2	1
−0.80 to −0.41	321	1, 293	801	395	92	25	9	2
−0.40 to −0.01	679	3, 748	1, 851	830	214	48	13	7
0.00 to 0.39	683	4, 171	2, 213	948	282	83	25	11
0.40 to 0.79	290	1, 347	1, 091	551	212	89	27	4
0.80 to 1.19	59	251	296	225	147	76	25	4
1.20 to 1.59	20	62	71	103	95	84	20	4
1.60 to 1.99	4	18	31	42	54	49	10	5
2.00 to 2.39	1	6	15	22	26	32	14	4
2.40 to 2.79		4	8	10	17	22	12	
2.80 to 3.19	1	1	3	3	6	15	5	2
3.20 and over		2	5	3	10	16	9	3
Total	2, 236	11, 377	6, 813	3, 318	1, 221	553	171	47
	Cents	*Cents*	*Cents*	*Cents*	*Cents*	*Cents*	*Cents*	*Cents*
Mean	−0. 08	0. 00	0. 04	0. 13	0. 45	0. 98	1. 13	0. 95
Standard error of mean	. 01	. 00	. 01	. 01	. 03	. 04	. 09	. 17
Average deviation	. 44	. 36	. 44	. 49	. 68	. 81	. 91	. 97
Approximate range [3]	6. 80	8. 40	8. 00	7. 60	9. 60	6. 40	5. 60	4. 40

SEASON 1929–30

	Bales	*Bales*	*Bales*	*Bales*	*Bales*	*Bales*	*Bales*	*Bales*
Under −2.80	6	15	11	6				
−2.80 to −2.41	4	7	4	3				
−2.40 to −2.01	9	24	11	3				
−2.00 to −1.61	27	30	21	7	5			
−1.60 to −1.21	70	107	54	16	9	1	1	
−1.20 to −0.81	233	340	151	58	15	1		
−0.80 to −0.41	807	1, 347	499	199	45	5		
−0.40 to −0.01	2, 024	4, 937	1, 984	766	155	26		
0.00 to 0.39	1, 656	5, 586	2, 615	941	237	59	2	1
0.40 to 0.79	521	1, 464	952	481	177	60	5	
0.80 to 1.19	186	310	224	161	115	55	6	
1.20 to 1.59	65	72	55	52	44	26	2	1
1.60 to 1.99	27	12	12	. 8	16	13	2	
2.00 to 2.39	13	6	4	4	9	12		
2.40 to 2.79	8	3	5	4	4	4		
2.80 to 3.19	2	1	3	1	2			
3.20 and over		3	3	1				
Total	5, 658	14, 264	6, 608	2, 711	833	262	18	2
	Cents	*Cents*	*Cents*	*Cents*	*Cents*	*Cents*	*Cents*	*Cents*
Mean	−0. 05	0. 00	0. 07	0. 14	0. 37	0. 73	0. 82	0. 68
Standard error of mean	. 01	. 00	. 01	. 01	. 02	. 04	. 17	
Average deviation	. 41	. 34	. 36	. 39	. 52	. 55	. 49	. 80
Approximate range [3]	8. 00	8. 00	9. 20	7. 60	4. 80	4. 00	3. 20	1. 60

SEASON 1930–31

	Bales	*Bales*	*Bales*	*Bales*	*Bales*	*Bales*	*Bales*	*Bales*
Under −2.80		1	1	1				
−2.80 to −2.41		3	9	2				
−2.40 to −2.01	4	5	10	6	4			
−2.00 to −1.61	6	15	20	10	5			
−1.60 to −1.21	14	41	69	29	11	1	1	
−1.20 to −0.81	62	176	205	84	32	7	1	
−0.80 to −0.41	151	922	829	298	127	24	2	
−0.40 to −0.01	663	3, 633	2, 518	926	272	54	5	
0.00 to 0.39	651	4, 403	3, 164	1, 172	376	74	7	
0.40 to 0.79	142	842	989	551	240	45	6	

See footnotes at end of table.

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TABLE 21.—*Frequency distribution of variations in prices [1] per pound received by growers for individual bales of specified staple lengths of Middling White [2] cotton from the average price received for 7/8-inch cotton of the same grade in selected local markets, seasons 1928–29 to 1932–33*—Continued

SEASON 1930–31—Continued

Variation (cents)	Shorter than 7/8 inch	7/8 inch	15/16 inch	1 inch	1 1/16 inches	1 1/8 inches	1 3/16 inches	1 1/4 inches and longer
	Bales	*Bales*	*Bales*	*Bales*	*Bales*	*Bales*	*Bales*	*Bales*
0.80 to 1.19	33	149	208	217	108	19	1	
1.20 to 1.59	6	21	59	56	38	8		
1.60 to 1.99		3	7	17	17	8		
2.00 to 2.39			2	1	3			
2.40 to 2.79			4	1				
2.80 to 3.19			1					
3.20 and over			2	1				
Total	1,732	10,214	8,097	3,372	1,233	240	23	
	Cents	*Cents*	*Cents*	*Cents*	*Cents*	*Cents*	*Cents*	*Cents*
Mean	−0.04	0.00	0.02	0.11	0.18	0.23	0.05	
Standard error of mean	.01	.00	.00	.01	.02	.04	.12	
Average deviation	.33	.31	.36	.40	.45	.45	.45	
Approximate range [3]	3.60	4.80	7.60	6.40	4.40	3.20	2.40	

SEASON 1931–32

	Bales	*Bales*	*Bales*	*Bales*	*Bales*	*Bales*	*Bales*	*Bales*
−2.00 to −1.61			1	1				
−1.60 to −1.21		2	2	2				
−1.20 to −0.81	4	8	10	11	3			
−0.80 to −0.41	22	145	132	105	12	4		
−0.40 to −0.01	169	1,275	1,261	826	156	11		
0.00 to 0.39	158	1,367	1,245	875	303	36	1	
0.40 to 0.79	29	98	191	223	113	19	1	
0.80 to 1.19	1	17	46	79	43	6		
1.20 to 1.59		1	9	14	11	1		
1.60 to 1.99				3	1			
2.00 to 2.39			1					
Total	383	2,913	2,898	2,139	642	77	2	
	Cents	*Cents*	*Cents*	*Cents*	*Cents*	*Cents*	*Cents*	*Cents*
Mean	0.00	0.00	0.03	0.08	0.23	0.29	0.33	
Standard error of mean	.02	.00	.00	.01	.02	.05		
Average deviation	.26	.24	.26	.30	.28	.30	.20	
Approximate range [3]	2.00	2.80	4.00	3.60	2.80	2.00	.40	

SEASON 1932–33

	Bales	*Bales*	*Bales*	*Bales*	*Bales*	*Bales*	*Bales*	*Bales*
−2.80 to −2.41		1	2					
−2.40 to −2.01								
−2.00 to −1.61			1					
−1.60 to −1.21		1	2	2	2			
−1.20 to −0.81	1	17	20	11	3	1		
−0.80 to −0.41	30	208	193	97	46	1	1	
−0.40 to −0.01	131	1,961	1,271	553	118	10		
0.00 to 0.39	136	1,919	1,450	853	154	18		
0.40 to 0.79	17	205	329	245	87	5	1	
0.80 to 1.19		17	31	43	13	1		
1.20 to 1.59		4	9	3	5	1		
1.60 to 1.99		1	1					
2.00 to 2.39			1	2				
2.40 to 2.79		1						
2.80 to 3.19		1						
Total	315	4,336	3,310	1,809	428	37	2	
	Cents	*Cents*	*Cents*	*Cents*	*Cents*	*Cents*	*Cents*	*Cents*
Mean	−0.02	0.00	0.04	0.11	0.12	0.14	0.14	
Standard error of mean	.02	.00	.01	.01	.01	.07	.60	
Average deviation	.26	.25	.28	.28	.35	.29	.60	
Approximate range [3]	1.60	5.60	4.80	3.60	2.80	2.40	1.20	

[1] Minus sign (−) means below the average price for 7/8-inch White cotton.
[2] Extra White cotton included.
[3] The approximate range was measured from the midpoint of the extreme classes.

TABLE 22.—*Comparative value per acre [1] of cotton of various staple lengths included in variety tests [2] in specified localities, seasons 1928–29 to 1932–33*

Location and staple length (1/32 inch)	Local-market premiums and discounts applied					Central-market premiums and discounts applied				
	1928	1929	1930	1931	1932	1928	1929	1930	1931	1932
Raymond, Miss. (valley land):[3]	*Dol.*	*Dol.*	*Dol.*	*Dol.*	*Dol.*	*Dol.*	*Dol.*	*Dol.*	*Dol.*	*Dol.*
23	------	------	------	------	21.77	------	------	------	------	20.77
24	------	------	67.38	------	------	------	------	60.10	------	------
26	92.55	------	------	23.27	------	90.06	------	------	21.07	------
27	------	------	59.33	------	------	------	------	53.21	------	------
28	112.23	------	66.46	25.46	37.02	112.23	------	66.46	25.46	37.02
29	------	140.72	------	27.69	33.84	------	140.72	------	27.69	33.84
30	121.37	------	86.17	30.02	35.53	123.03	------	89.53	31.38	36.32
31	------	126.37	84.21	32.89	37.06	------	129.16	87.50	34.39	37.89
32	103.39	131.22	75.47	32.83	35.21	107.44	140.39	81.67	36.07	37.15
33	99.91	------	80.10	31.61	30.10	103.81	------	86.79	34.73	31.74
34	96.18	140.16	79.90	32.39	33.12	102.58	153.79	91.48	37.55	37.15
35	114.97	152.83	76.91	26.19	23.60	122.58	167.79	87.92	30.33	26.50
36	101.22	149.63	71.40	30.30	28.81	107.17	164.24	84.65	39.30	33.84
37	141.80	150.92	------	24.56	------	150.16	165.59	------	31.86	------
38	83.01	138.74	50.63	------	------	91.02	158.57	68.37	------	------
39	------	131.12	------	------	------	------	149.69	------	------	------
40	------	139.50	------	------	------	------	182.74	------	------	------
Raymond, Miss. (hill land):[3]										
22	------	------	60.86	------	------	------	------	54.20	------	------
23	------	------	------	------	24.68	------	------	------	------	23.54
24	43.26	------	46.79	19.43	------	42.09	------	41.82	17.59	------
25	------	------	54.03	------	------	------	------	48.28	------	------
26	45.99	------	62.92	21.86	------	44.77	------	56.20	19.81	------
27	------	86.40	53.51	------	23.79	------	81.37	47.79	------	22.73
28	------	98.70	53.29	19.85	23.31	------	98.70	53.29	19.85	23.31
29	------	82.51	53.43	18.35	29.16	------	82.51	53.43	18.35	29.16
30	48.11	91.02	46.96	20.44	27.94	48.77	93.04	48.82	21.38	28.56
31	------	------	45.65	23.18	29.42	------	------	47.43	24.24	30.08
32	41.16	92.65	53.97	19.38	26.63	42.77	99.17	58.49	21.29	28.11
33	44.11	90.45	------	22.74	24.76	45.84	96.84	------	24.99	26.11
34	51.17	92.98	------	21.55	24.59	54.58	102.09	------	25.00	27.60
35	52.47	91.44	34.97	18.52	23.89	55.96	100.39	39.99	21.47	26.84
36	41.23	81.23	------	16.95	21.75	43.66	89.17	------	22.01	25.54
37	------	87.50	------	------	------	------	96.04	------	------	------
38	------	64.64	------	------	------	------	73.82	------	------	------
Holly Springs, Miss. (valley land):[4]										
22	------	102.22	------	------	------	------	96.35	------	------	------
24	------	------	69.86	------	27.43	------	------	62.38	------	26.18
26	110.89	------	68.99	------	------	107.92	------	61.97	------	------
27	------	------	63.23	15.13	------	------	------	56.80	13.71	------
28	99.16	111.65	------	11.38	20.44	99.16	111.65	------	11.38	20.44
29	------	------	65.08	13.39	23.00	------	------	65.08	13.39	23.00
30	124.45	------	72.67	------	25.29	126.14	------	75.47	------	25.84
31	------	104.26	65.23	22.30	26.32	------	106.58	67.72	23.32	26.91
32	125.41	121.37	63.48	23.06	30.33	130.29	129.90	68.66	25.32	31.98
33	111.61	115.04	62.68	18.58	27.14	115.91	123.14	67.79	20.39	28.63
34	110.12	133.34	66.14	11.50	29.13	117.41	146.46	75.50	13.32	32.70
35	123.60	107.54	------	34.65	28.36	131.82	118.05	------	40.14	31.84
36	106.83	112.50	------	30.66	29.57	113.06	123.47	------	39.78	34.68
37	130.98	103.28	54.29	------	27.24	138.66	113.35	64.05	------	31.97
38	101.59	103.55	------	15.29	------	111.34	118.37	------	23.01	------
39	------	101.91	------	------	------	------	116.42	------	------	------
Holly Springs, Miss. (hill land):[4]										
22	------	------	34.36	------	------	------	------	30.64	------	------
23	------	------	26.90	------	25.95	------	------	24.13	------	24.76
24	73.26	------	25.44	------	------	71.27	------	22.82	------	------
26	64.28	------	------	------	20.14	62.53	------	------	------	19.24
27	------	85.82	26.40	29.94	18.29	------	80.79	23.66	27.10	17.47
28	------	83.38	27.54	26.70	23.73	------	83.38	27.54	26.70	23.73
29	------	74.49	30.16	30.15	24.44	------	74.49	30.16	30.15	24.44
30	69.59	78.34	24.74	28.85	24.26	70.55	80.10	25.70	30.17	24.80
31	------	------	23.73	32.92	24.24	------	------	24.64	34.43	24.78
32	78.88	79.28	------	39.44	23.95	82.01	84.89	------	43.34	25.27
33	67.00	87.10	------	36.08	22.66	69.64	93.28	------	39.64	23.90
34	63.98	97.72	20.63	28.75	21.64	68.30	107.41	23.56	33.32	24.30
35	71.85	91.28	------	44.63	15.97	76.67	100.25	------	51.77	17.92
36	52.01	78.80	------	29.34	------	55.10	86.52	------	38.11	------
37	------	80.18	------	45.63	------	------	88.00	------	59.28	------
38	------	68.19	------	------	------	------	77.96	------	------	------

See footnotes at end of table.

TABLE 22.—*Comparative value per acre [1] of cotton of various staple lengths included in variety tests [2] in specified localities, seasons 1928–29 to 1932–33*—Continued

Location and staple length (1/32 inch)	Local-market premiums and discounts applied					Central-market premiums and discounts applied				
	1928	1929	1930	1931	1932	1928	1929	1930	1931	1932
Poplarville, Miss.:[5]	*Dol.*	*Dol.*	*Dol.*	*Dol.*	*Dol.*	*Dol.*	*Dol.*	*Dol.*	*Dol.*	*Dol.*
22			31.09					27.77		
24	47.16				8.05	45.88				7.68
25			27.95					25.13		
26	56.23		27.49	21.43	10.45	54.75		24.65	19.40	9.99
27		47.86	26.94	17.42			45.06	24.17	15.79	
28		34.90		27.35	11.34		34.90		27.35	11.34
29		63.98	35.62	26.27	8.97		63.98	35.62	26.27	8.97
30	57.74	62.10	34.34	25.66	15.86	58.53	63.49	35.66	26.83	16.21
31			29.99	24.91				31.13	26.05	
32	46.42	64.92	28.04	28.82	13.28	48.25	69.51	30.32	31.67	14.01
33	56.80	55.71		27.65	13.04	59.04	59.65		30.36	13.75
34	59.76	49.35		24.97	12.45	63.74	54.21		28.93	13.98
35	62.46	51.95	15.68	27.69	6.99	66.63	57.05	17.90	32.07	7.85
36	49.98	65.20		28.11	10.87	52.94	71.59		36.50	12.76
37		57.10					62.66			
38		19.66		17.47			22.46		26.28	
Stoneville, Miss.:[6]										
22		107.04	39.92				100.78	35.68		
24	113.44	112.96			11.83	110.38	106.37			11.29
25	104.81	104.92	37.98	7.86		102.04	98.86	34.10	7.12	
26			35.71					31.97		
27		99.97		5.46			94.19		4.95	
28	123.18	105.89		10.07	10.69	123.18	105.89		10.07	10.69
29	108.92		36.26	10.70		108.92		36.26	10.70	
30	101.80		40.97	10.88		103.19		42.53	11.37	
31	107.43	109.90	41.97	9.53	13.53	108.91	112.36	43.58	9.96	13.84
32	97.94	102.85	32.42	9.46	12.77	101.74	110.10	35.07	10.39	13.47
33	97.90		37.89	16.12	15.01	101.70		40.96	17.70	15.83
34		99.17	35.44	14.01	15.77		108.88	40.45	16.24	17.70
35	112.45	100.42	34.93	16.69	17.02	119.93	110.29	39.90	19.35	19.12
36	117.23	115.86	36.35	14.77	12.17	124.25	127.28	42.93	19.16	14.30
37	134.49	92.09	32.91	14.09	16.70	142.41	101.04	38.87	18.25	19.61
38	103.25			13.35	13.32	113.21			20.05	17.79
39				16.69	14.44				25.11	19.30
Auburn, Ala.:[7]										
20			44.57					39.58		
24			50.00					44.48		
26			49.04		17.90			43.58		17.13
27	74.30	63.72		25.10		72.71	60.04		22.86	
28	92.28	68.57	44.63	27.36	20.86	92.28	68.57	44.63	27.36	20.86
29	92.17	56.30	45.69	27.68	24.74	92.17	56.30	45.69	27.68	24.74
30	84.09	71.23	45.32	24.23	17.50	85.24	72.82	47.18	25.27	17.87
31	87.64			25.44	19.59	88.84			26.53	20.00
32	75.87	71.58		25.50	23.24	78.85	76.59		27.85	24.43
33	102.50	57.52	37.74	22.32	22.60	106.55	61.53	41.03	24.38	23.77
34	92.85	56.04		22.48		99.04	61.44		25.84	
35	91.73	44.20		19.68	20.27	97.88	48.46		22.60	22.63
36	71.51	54.42	30.14			75.71	59.63	35.98		
37		37.53			14.10		41.10			16.41
Prattville, Ala.:[7]										
25				27.99	20.83				25.52	19.92
26		75.70	18.50	29.63			71.32	16.46	26.98	
27		78.20		28.04	20.47		73.69		25.57	19.60
28	110.61	70.25	19.47	29.89	20.34	110.61	70.25	19.47	29.89	20.34
29		74.93	13.47	26.09	21.17		74.93	13.47	26.09	21.17
30	112.42	73.15	12.75	28.49	22.19	113.93	74.78	13.27	29.71	22.67
31		69.37		25.36	18.05		70.91		26.44	18.43
32	108.18	65.54	17.06	26.79	16.80	112.29	70.11	18.55	29.27	17.66
33		65.14	12.78	25.26			69.69	13.88	27.57	
34	85.12	63.82	14.19			90.74	70.00	16.34		
35		61.83					67.79			
36	119.88	61.24	9.99			126.96	67.14	11.92		
40	91.00					111.58				
Marianna, Ark.:[8]										
24			30.15		21.24			26.73		20.22
25					22.80					21.70
27	79.53	64.89	17.38			77.48	61.19	15.47		
28	79.82	55.24	26.91	24.98		79.82	55.24	26.91	24.98	
29	86.53	53.92	26.32	24.52	15.54	86.53	53.92	26.32	24.52	15.54
30	68.73	64.34	25.40	18.52	19.53	69.67	65.73	26.46	19.44	20.00
31	92.47	53.66	22.21	24.23	19.87	93.73	54.82	23.12	25.44	20.34
32	81.37	57.44	23.09	26.75	21.34	84.50	61.36	25.12	29.63	22.59
33	98.90	61.47	20.80	25.54	20.78	102.73	65.67	22.63	28.30	21.99

See footnotes at end of table.

TABLE 22.—*Comparative value per acre [1] of cotton of various staple lengths included in variety tests [2] in specified localities, seasons 1928–29 to 1932–33*—Continued

Location and staple length (1/32 inch)	Local-market premiums and discounts applied					Central-market premiums and discounts applied				
	1928	1929	1930	1931	1932	1928	1929	1930	1931	1932
	Dol.	*Dol.*	*Dol.*	*Dol.*	*Dol.*	*Dol.*	*Dol.*	*Dol.*	*Dol.*	*Dol.*
Marianna, Ark.—Contd.										
34	78.52	68.03	19.10	26.84	20.77	83.61	74.48	22.00	31.52	23.51
35	89.71	62.17	------	24.81	17.68	95.52	68.08	------	29.13	20.00
36	69.60	64.06	22.03	26.65	17.52	73.64	70.08	26.34	35.34	20.79
37	------	51.81	------	------	13.20	------	56.67	------	------	15.65
38	------	41.44	------	18.15	------	------	47.15	------	28.21	------
Athens, Ga.:[9]										
24	------	------	42.54	26.78	23.30	------	------	37.78	24.37	22.31
26	155.88	87.06	40.05	45.02	27.09	151.67	81.95	35.66	40.97	25.95
27	------	------	32.64	------	------	------	------	29.07	------	------
28	175.99	91.41	39.36	29.09	27.98	175.99	91.41	39.36	29.09	27.98
29	------	------	35.55	------	------	------	------	35.55	------	------
30	169.46	86.63	34.71	30.38	21.19	171.80	88.61	36.12	31.70	21.62
31	------	------	45.21	------	------	------	------	47.07	------	------
32	172.02	91.95	37.33	38.69	27.77	178.83	98.53	40.59	42.36	29.19
33	------	------	38.28	29.98	28.38	------	------	41.62	32.77	29.82
34	161.17	92.92	35.67	30.48	28.50	172.16	102.13	41.10	35.04	31.81
35	------	------	35.13	------	------	------	------	40.46	------	------
36	170.24	98.13	28.50	28.96	25.37	180.59	107.84	34.02	37.15	29.53
37	------	------	28.29	------	------	------	------	33.83	------	------
38	164.78	80.85	26.16	35.07	16.86	180.91	92.61	35.95	51.89	22.10
40	133.60	82.49	------	------	------	164.51	108.69	------	------	------
Experiment, Ga.:[10]										
26	------	------	64.73	35.79	------	------	------	57.51	32.54	------
27	------	80.98	------	31.76	------	------	76.21	------	28.93	------
28	91.44	79.91	62.25	29.74	23.08	91.44	79.91	62.25	29.74	23.08
29	------	79.30	------	31.98	------	------	79.30	------	31.98	------
30	106.42	81.14	57.03	34.30	23.09	107.86	82.97	59.37	35.80	23.57
31	------	80.04	------	------	26.10	------	81.85	------	------	26.64
32	90.02	83.98	50.96	27.25	22.93	93.54	89.99	55.39	29.79	24.10
33	116.12	86.75	63.76	------	26.80	120.66	92.95	69.37	------	28.18
34	109.77	75.92	64.51	28.30	22.96	117.02	83.44	74.33	32.57	25.60
35	110.48	74.28	51.04	------	23.75	117.83	81.64	58.77	------	26.48
36	92.02	73.61	------	------	------	97.41	80.86	------	------	------
37	------	64.35	62.00	------	18.73	------	70.70	74.08	------	21.78
39	------	------	45.73	------	------	------	------	62.70	------	------
Clemson College, S. C.:[11]										
26	------	53.86	------	------	------	------	50.86	------	------	------
28	88.72	53.38	36.92	19.28	------	88.72	53.38	36.92	19.28	------
29	------	53.37	42.88	19.24	------	------	53.37	42.88	19.24	------
30	74.44	53.04	39.08	18.93	27.00	75.40	54.18	40.55	19.73	27.55
31	------	61.16	44.15	17.37	31.75	------	62.47	45.80	18.11	32.41
32	83.65	------	45.78	------	26.98	86.73	------	49.48	------	28.33
33	79.03	56.65	38.19	------	32.32	81.88	60.52	41.24	------	33.98
34	55.50	------	38.76	------	31.97	58.97	------	44.25	------	35.63
35	------	54.91	------	------	26.86	------	60.08	------	------	29.92
36	73.55	48.15	------	------	25.39	77.65	52.66	------	------	29.56
37	78.54	------	34.09	------	------	82.94	------	40.16	------	------
38	80.56	------	28.44	------	------	87.90	------	38.13	------	------
40	69.62	------	------	------	------	84.22	------	------	------	------
Jackson, Tenn.:[12]										
24	126.48	------	------	------	------	122.84	------	------	------	------
28	99.46	------	31.04	------	------	99.46	------	31.04	------	------
30	113.65	132.73	31.67	26.98	------	115.33	135.91	32.96	28.28	------
31	82.91	127.06	26.16	------	26.75	84.12	136.65	27.24	------	27.39
32	109.36	120.09	------	------	29.27	113.97	132.70	------	------	30.98
33	------	------	------	28.54	25.61	------	------	------	31.51	27.11
34	------	------	25.62	28.99	23.71	------	------	29.50	33.87	26.85
35	102.19	------	------	------	------	109.43	------	------	------	------
36	------	108.29	------	------	28.00	------	119.55	------	------	33.27
37	------	------	------	------	21.34	------	------	------	------	25.35
Murfreesboro, Tenn.:[12]										
26	28.95	------	------	------	------	28.12	------	------	------	------
28	20.92	------	------	------	------	20.92	------	------	------	------
30	35.99	------	31.84	------	------	36.52	------	33.16	------	------
31	------	60.04	28.20	16.01	20.65	------	61.48	29.37	16.79	21.14
32	28.43	54.05	28.96	23.47	23.27	29.61	58.13	31.51	25.92	24.64
33	------	42.18	25.91	23.41	23.33	------	45.36	28.18	25.86	24.70
34	------	56.95	25.41	20.24	22.20	------	62.93	29.25	23.65	25.15
35	------	------	------	------	19.79	------	------	------	------	22.40
36	31.12	40.77	------	------	------	33.07	45.02	------	------	------

See footnotes at end of table.

TABLE 22.—*Comparative value per acre*[1] *of cotton of various staple lengths included in variety tests*[2] *in specified localities, seasons 1928–29 to 1932–33*—Continued

Location and staple length (1/32 inch)	Local-market premiums and discounts applied					Central-market premiums and discounts applied				
	1928	1929	1930	1931	1932	1928	1929	1930	1931	1932
Baton Rouge, La.[13] (bluff land):	*Dol.*	*Dol.*	*Dol.*	*Dol.*	*Dol.*	*Dol.*	*Dol.*	*Dol.*	*Dol.*	*Dol.*
26	48.50	44.61	------	19.08	------	47.14	41.99	------	17.20	------
28	79.87	64.86	57.16	26.99	18.81	79.87	64.86	57.16	26.99	18.81
29	------	65.58	------	32.41	19.40	------	65.58	------	32.41	19.40
30	93.63	84.10	57.96	------	21.10	94.96	85.98	60.28	------	21.58
31	81.54	------	------	------	24.07	82.70	------	------	------	24.62
32	81.00	73.71	50.29	28.61	22.67	84.32	78.96	54.66	31.57	23.94
33	------	------	------	31.97	24.06	------	------	------	35.28	25.40
34	88.70	67.72	------	29.83	22.20	94.85	74.37	------	34.81	25.01
35	88.63	------	------	27.82	23.60	94.75	------	------	32.47	26.58
36	79.75	64.18	42.26	22.65	17.16	84.66	70.43	50.44	29.74	20.25
37	81.66	76.95	36.30	25.46	17.78	86.71	84.48	43.24	33.44	20.97
38	70.93	72.83	51.70	21.02	------	78.05	83.32	70.80	32.20	------
39	------	49.41	------	------	------	------	56.48	------	------	------
Baton Rouge, La.[13] (alluvial land):										
26	53.16	------	55.35	------	20.20	51.68	------	49.19	------	19.26
28	59.13	92.17	51.06	34.21	------	59.13	92.17	51.06	34.21	------
30	58.82	94.66	61.83	26.83	18.71	59.66	96.71	64.30	28.12	19.14
31	------	------	------	37.01	19.35	------	------	------	38.79	19.79
32	62.93	83.57	59.83	31.57	21.38	65.48	89.46	65.02	34.84	22.58
33	49.40	69.18	44.66	17.71	21.36	51.40	74.10	48.51	19.54	22.56
34	------	80.78	------	34.73	19.80	------	88.68	------	40.53	22.30
35	------	72.35	------	31.75	16.34	------	79.40	------	37.05	18.38
36	63.40	83.22	50.84	34.22	20.94	67.27	91.33	60.57	44.95	24.70
37	------	82.54	58.99	37.92	------	------	90.57	70.26	49.81	------
38	51.07	79.78	51.77	------	10.99	56.18	91.28	70.81	------	14.76
39	------	50.94	49.35	------	------	------	58.23	67.42	------	------

[1] The comparative value per acre represents the value of the lint cotton and cottonseed minus the cost of picking, ginning, and bagging and ties. Value of the cottonseed was based on the average price received by growers as reported by the Bureau of Agricultural Economics. Prevailing rates for picking, ginning, and bagging and ties were used in calculating the costs. Average prices received by growers in selected local markets in the United States for Middling 7/8-inch white cotton were used as a basis. To this basis were applied local and central-market staple premiums and discounts.

[2] Cotton-variety tests as reported by State agricultural experiment stations. Data for highest yielding variety for each staple length for each year were used.

[3] Miss. Agr. Expt. Sta. Bulls. 262 and 271 (*41*), 287 and 299 (*40*) and mimeographed report for 1932.

[4] Miss. Agr. Expt. Sta. Bulls. 264 and 272 (*2*), 286 (*28*), 296 (*11*), and mimeographed report for 1932.

[5] Miss. Agr. Expt. Sta. Bulls. 266 and 274 (*31*), 285 (*34*), 297 (*38*). Data for 1932 obtained in unpublished form from Mississippi Agricultural Experiment Station.

[6] Cotton-variety tests as reported by the Delta Experiment Station, Stoneville, Miss. (Mimeographed reports.)

[7] Data on yields and staple length obtained in unpublished form from H. B. Tisdale, Department of Agronomy and Soils, Alabama Polytechnic Institute.

[8] Cotton-variety tests as reported by the Arkansas Agricultural Experiment Station.(Mimeographed reports.)

[9] Cotton-variety tests as reported by the Georgia State College of Agriculture. (Mimeographed reports.)

[10] Ga. Agr. Expt. Sta. Circ. 83 (*5*), 87 (*20*), 90 (*7*), 100 (*6*), and mimeographed report for 1932.

[11] S. C. Agr. Expt. Sta. Circ. 35 (*9*), 40 (*35*), and Agricultural Education (*13*).

[12] Data on yields and staple lengths obtained in unpublished form from the Tennessee Agricultural Experiment Station.

[13] La. Agr. Expt. Sta. Bull. 207 (*8*) and mimeographed reports for 1928, 1930, 1931, and 1932.

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Silviculturist, Southern Forest Experiment Station
Forest Service

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ARTIFICIAL REFORESTATION IN THE SOUTHERN PINE REGION

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INTRODUCTION

Much land in the southern pine region that is better suited to forest production than to any other use has been rendered incapable of prompt natural restocking with timber species, principally through undesirable logging methods and through fire. If this land is to produce merchantable forest products within the next 40 to 100 years, it must be reforested artificially. Artificial reforestation involves collecting tree seed, growing tree seedlings in nurseries, and planting the seedlings. The purpose of this bulletin is to set forth principles governing this work and the technic involved, on the basis of 10 years' study and experimentation by the Southern Forest Experiment Station and of the station's acquaintance with State and private planting throughout the southern pine region.

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The ranges of the principal southern pine species are shown in figure 1.

Accurate figures on the extent of nonrestocking land in the region are unavailable, pending completion of the forest survey now being conducted by the United States Forest Service. Even when completed, the survey will not have shown exactly what portions of the land now nonproductive are incapable of restocking or what portions can be planted with promise of good financial returns. (Much light will be thrown on the latter subject by the productivity attained under good forest management by the large areas on which natural reproduction is already in progress.) There is good reason for assuming, however, that the nonrestocking southern pine land on which

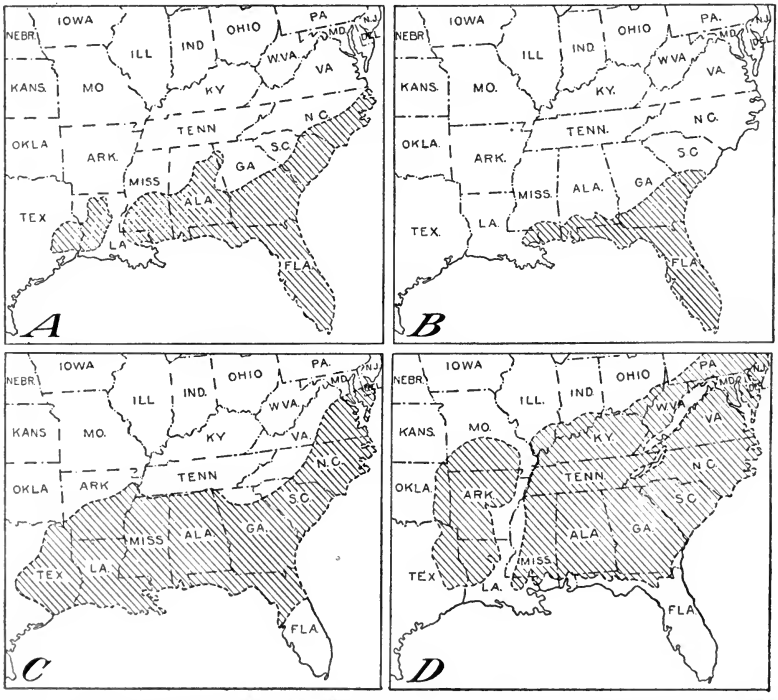

FIGURE 1.—Natural ranges of longleaf (*A*), slash (*B*), loblolly (*C*), and shortleaf (*D*) pines.

planting would be desirable within the next 20 years exceeds 5,000,000 acres. On a large additional area it would seem justifiable to augment and improve the natural stands by planting.

The feasibility of planting for timber production depends on the ease and certainty with which trees can be established in the field, the cheapness with which they can be produced and planted, and, in most cases, the financial returns that can be obained. Climate, topography, characteristics of the principal species, and geographic location combine to make artificial reforestation at least as easy and certain, and economically as promising, in the southern pine region as in any other region of the United States.

Mean annual temperature, a rough index of growing conditions, ranges from 55° F. in Delaware and Maryland to 75° in Florida.

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Mean annual rainfall ranges from 40 inches in Maryland and in the extreme western portion of the shortleaf pine type in Texas, to more than 60 inches in the extreme western portion of Florida and in the extreme southern portions of Alabama and Mississippi (*34*).[1] Through most of the region, the topography is flat or only moderately rolling. A large part of the land in need of planting is wholly free from surface stones.

The region is readily accessible to markets for forest products.

Four principal species make up practically the entire cut of southern pine: Longleaf pine (*Pinus palustris* Mill.), slash pine (*P. caribaea* Morel.), loblolly pine (*P. taeda* L.), and shortleaf pine (*P. echinata* Mill.). One or more of these species compose an important part of the commercial forests of each of the following 13 States: Delaware, Maryland, Virginia, North Carolina, South Carolina, Georgia, Florida, Alabama, Mississippi, Louisiana, Texas, Arkansas, and Oklahoma.

All four of the principal southern pine species produce wood of high technical quality and utility. Within the sizes ordinarily attained by the trees they are unexcelled for structural timbers. They yield poles, piling, railroad ties, and other products of great value and are being used increasingly for kraft paper. Longleaf and slash pine yield the entire national output of naval stores (turpentine and rosin).

These four species are among the most rapidly growing and most highly productive timber trees in the United States. The extreme openness of the existing old-growth stands, only a small percentage of which contain so much as 12,000 board feet per acre, is due to lack of management, and particularly to indiscriminate burning. Likewise the yields of the existing second-growth stands of merchantable size, ordinarily from 1,000 to 10,000 board feet per acre, are much below their potential yields, owing to present utilization practices. Yields of fully stocked second-growth stands subjected only occasionally to fire and cut under extremely close utilization practices are given in table 1. On the better sites, plantations may exceed the yields given in the table. Yields of turpentine under up-to-date practices are given in table 2.

TABLE 1.—*Normal yields per acre of unmanaged natural stands of southern pines on approximately average sites*[1]

Age	Longleaf pine			Slash pine			Loblolly pine			Shortleaf pine		
	Cords	*Board feet*	*Cubic feet*	*Cords*	*Board feet*	*Cubic feet*	*Cords*	*Board feet*	*Cubic feet*	*Cords*	*Board feet*	*Cubic feet*
15 years	7	200	825	27	1,500	2,150	18	850	1,600	------	--------	1,010
20 years	14	1,000	1,325	35	4,000	2,700	27	5,000	2,300	18	250	1,670
25 years	21	3,000	1,800	42	8,000	3,250	37	11,000	3,100	31	2,800	2,400
30 years	28	5,000	2,200	48	13,000	3,750	46	17,000	3,850	41	6,900	3,120
35 years	33	8,000	2,700	54	17,500	4,250	54	23,000	4,600	49	12,000	3,780
40 years	39	11,000	3,100	58	22,000	4,600	61	28,500	5,200	56	17,800	4,380
45 years	43	14,000	3,550	62	25,500	4,950	67	33,500	5,700	61	23,000	4,880
50 years	48	17,500	3,950	65	28,000	5,300	71	37,500	6,150	66	27,200	5,320
55 years	52	20,500	4,300	67	30,500	5,500	75	40,500	6,450	70	30,700	5,680
60 years	55	23,500	4,650	69	32,000	5,750	78	43,000	6,700	73	33,500	6,000

[1] Exclusive of naval stores yields, and of intermediate yields such as wood cut in thinnings. Table based on (*31, tables 39, 46, 53, 71, 78, 85, 103, 135, 142, 149.*) The following site indices (dominant heights at 50 years) are taken as average: Longleaf pine, 70 feet; slash pine, 80 feet; loblolly pine, 90 feet; shortleaf pine, 70 feet. Yields are figured as follows: In cords, from rough wood, all trees 4 inches d. b. h. or more; in board feet, by International (¼-inch) rule, from 1-foot stump height to a top diameter inside bark of 5 inches; in cubic feet, from total peeled volume of all trees 2 inches d. b. h. or more.

[1] Italic numbers in parentheses to Literature Cited, p. 108.

TABLE 2.—*Average annual yields*[1] *of turpentine per crop of 10,000 second-growth trees, by diameter, species, and stand density*

Diameter breast high	Slash pine		Longleaf pine, open stand
	Open stand	Dense stand	
	Barrels	*Barrels*	*Barrels*
5 inches	12		
6 inches	19		20
7 inches	26	13	26
8 inches	34	22	32
9 inches	41	32	38
10 inches	48	40	44
11 inches	56	49	50
12 inches	63	59	56

[1] Table based on (*39, figs. 20, 22*). Production of 1 barrel of turpentine (50 gallons) is accompanied by production of approximately 2½ barrels of rosin.

The high productivity and early merchantability indicated in the tables result from the combination of long growing season and adequate rainfall with species characteristics.

The cost of establishing forest plantations is potentially lower in the South than in any other forest region of the United States, because of the favorable climate and topography and because the southern pines can almost invariably be planted as 1-year-old seedlings instead of as the older seedlings or transplants commonly used in other regions.

If planting is done judiciously and skillfully, there is every reason to believe that the financial returns from the planted stands will be almost as good as those from stands produced naturally. In some instances they will probably be better. This probability is particularly high for longleaf pine, which is relatively difficult to reproduce by natural means but which can be planted at about the same expense as the other species.

Aside from direct financial returns to an individual landowner through sale or use of forest products such as saw timber, piling, poles, and pulpwood, several kinds of benefits from plantations call for consideration. A moderate planting program undertaken at the right time may make possible perpetual operation of a sawmill or pulp mill. Federal agencies, by establishing extensive plantations, may create a source of future public income from districts the tax revenues from which have practically disappeared because of exhaustion of forest resources. In certain localities, particularly in the silt loam uplands of northern Mississippi and the piedmont section of central Georgia, forest planting appears to offer the best means of controlling erosion, simultaneously defraying part of the cost of control by providing salable products. Plantations have value also for game management.

Forest planting in the southern pine region is of very recent development. A few existing plantations are known to have been established in the region by farm owners as far back as 1907, 1896, and 1892, usually with wild stock. These early plantations, however, make a pitifully meager showing in comparison with those established during the same period in New England and New York. In 1911 the Forest Service attempted to reforest artificially approxi-

mately 900 acres on what are now the Choctawhatchee and Ocala National Forests, in Florida, partly by planting and partly by direct seeding. This venture, undertaken on what are perhaps the poorest sites in the South, failed almost entirely. During the decade 1911–20 sporadic private experiments with wild stock increased slightly, and several planters in the Atlantic Coast States established southern pine plantations that have developed satisfactorily. For all these early plantations, establishment costs were so high as to indicate that the methods used were unsuited for any extensive reforestation program. Up to and including 1919, the area successfully planted with southern pines by all agencies combined totaled probably less than 500 acres.

In the winter of 1919–20 the Great Southern Lumber Co., in southern Louisiana, began artificial planting on a large scale, at a moderate cost per acre. By the spring of 1926 it had established plantations totaling 12,700 acres. In 1933 the area planted by this company reached a total of 28,500 acres.

Since 1926, planting has become rather general throughout the southern pine region. Information concerning seed and improved nursery practice and planting methods has been made available, together with much other information relative to the southern pines, in a series of Forest Service and other bulletins. Rapid progress has been made both by lumber and paper companies and by farmers and other owners of small tracts. Part of this progress is traceable to the activities of State forestry departments and to Federal aid extended under provisions of the Clarke-McNary Act of 1924. The approximate extent of planting by all agencies combined is shown in table 3.

TABLE 3.—*Extent of forest planting*[1] *in the 13 States lying wholly or partly within the southern pine region, by all agencies*

State	Before 1928	1928	1929	1930	1931	Total	Total for States planting southern pines almost exclusively
	Acres	*Acres*	*Acres*	*Acres*	*Acres*	*Acres*	*Acres*
Delaware	70	60	25	122	99	376	
Maryland	1,381	133	220	336	521	2,591	
Virginia	337	47	349	316	401	1,450	
North Carolina	1,525	306	544	270	468	3,113	
South Carolina			112	481	745	1,338	1,338
Georgia	1,500	6	800	2,542	154	5,002	5,002
Florida	966	0	34	1,468	1,867	4,335	4,335
Alabama	89	50	328	266	34	767	767
Mississippi				535	594	1,129	1,129
Louisiana	19,540	9,273	10,583	6,556	2,474	48,426	48,426
Texas				260		260	260
Arkansas	772	0	0	73	9	854	854
Oklahoma	2,538	28	121	181	147	3,015	
Total	28,718	9,903	13,116	13,406	7,513	[2] 72,656	[3] 62,111
Cumulative total	28,718	38,621	51,737	65,143	72,656		

[1] Table based on reports submitted by State foresters under sec. 4 of the Clarke-McNary Act. Includes not only pine plantations but all forest plantations reported, and not only plantations that survived but those that failed or were destroyed. It is not believed that any considerable acreage of southern pine plantations was omitted from the State foresters' reports.

[2] Of this total 49,171 acres (67 percent) was planted by lumber and paper companies and 15,452 acres (21 percent) by farmers.

[3] Of this total 48,712 acres (78 percent) was planted by lumber companies and 8,738 acres (14 percent) by farmers.

Prior to the expansion of planting on national forests in 1933 as a phase of Emergency Conservation Work, lumber and paper companies dominated the field of forest planting in the southern pine region. At the end of the calendar year 1931, such companies had planted 67 percent of the total area artificially reforested in the 13 States lying wholly or partly within the southern pine region. More than 20 lumber and paper companies had planted 78 percent of the area reforested artificially in South Carolina, Georgia, Florida, Alabama, Mississippi, Louisiana, and Texas, the States in which practically all forest planting has been done with southern pines. In these same States, some 787 farmers had planted a total of only 13.9 percent of the area reforested artificially.

Most of the early work was done with loblolly pine. In some instances this species was used on longleaf pine land, for which loblolly pine is usually unsuitable. About 1926, slash pine became the favored species for planting use. Slash does far better on cut-over longleaf land than loblolly, at least within or near its natural range. Meanwhile the mattock had been replaced in the South as the common planting tool by an iron planting bar that greatly expedited the work.

The first successful commercial plantation of longleaf pine was established in 1924. Previous to that time it had been considered difficult or impossible to establish this species artificially. By 1927–28 studies and large-scale tests by a number of agencies had demonstrated that longleaf pine, if skillfully handled, can be planted as cheaply and effectively as the other species. Since the species is preeminently suited to certain sites and conditions, this marked a great step forward.

Later noteworthy developments include reduction of cost by improvement of equipment and simplification of procedure; improvements in the quality of plantations through better choice of species, mixture of species, and the use of closer or wider spacing to meet certain exacting local conditions; and better organization of planting work through systematic planning and careful records.

Direct seeding, that is, scattering seed broadcast or sowing it in furrows, on prepared spots, or on areas prepared by harrowing, has been tried in some reforestation projects in the South, principally in order to avoid the expense of money and effort involved in growing seedlings in a nursery. Occasionally the theory is advanced that sowing the seed directly on the site where it is desired to grow the trees insures sounder and more normal development of the root system than is possible in the case of trees transplanted from a nursery.

Records are available of the results of efforts to establish southern pines by direct seeding on 34 tracts, plots, or groups of plots on 21 different areas in 18 localities in the southern pine region, from Maryland to Texas. These figures include no attempts in which there is reason to doubt the viability of the seed used. On only 6 of the tracts, plots, or groups of plots (17.6 percent) was direct seeding clearly and consistently successful. On only 10 others (29.4 percent) could the process be called even partly or possibly successful. Of the total 16 plantings that constitute clear or possible successes, 10 involved elaborate site preparation such as clearing, plowing, and

harrowing, or the use of prohibitively expensive quantities of seed, or both; success was attained in one instance by sowing 25 pounds of longleaf pine seed per acre, and in another by sowing 13.5 pounds of loblolly pine seed per acre.

A summary of these records indicates that in regard to successful establishment by direct seeding the principal southern pine species rank as follows, in order of increasing success: Longleaf, slash, loblolly, shortleaf. This is the same order in which they rank as to size of seed, longleaf pine having the largest seed and shortleaf the smallest. The coincidence is interesting in relation to the reasons given for failure of direct seeding on the 25 tracts, plots, or groups of plots for which such reasons were recorded. Failure was attributed, wholly or partly, to birds on 12 tracts, to rodents on 9, to insufficient seed-bed moisture on 7, and to one or more other causes on lesser numbers.

Planted stands usually make better initial growth than direct-seeded stands. The most obvious reason for this is the good start obtained by seedlings on the cultivated and artificially watered soil of the nursery. Generally, a 1-year-old seedling of slash pine grown in a nursery is as large as one 2 or 3 years old that has grown wild in the woods or on cut-over land, and a top-grade nursery-grown longleaf pine seedling 1 year old is as large as an ordinary 5-year-old or older longleaf pine seedling grown naturally.

It would seem inadvisable to attempt direct seeding on a commercial scale by any method yet demonstrated.

Another scheme that has been tried without much success as a method of establishing stands of southern pine is to plant wild seedlings dug up in the forest or in old fields. It is true that the earliest successful plantations in the South, and a few excellent later plantations, were established with wild stock, and that wild stock still occasionally fills a need in experimental work, in a small or moderate-sized private planting, or in a preliminary demonstration by a public agency. In general, however, wild stock is too hard to find when wanted, too expensive to lift, and too uncertain in survival and growth to justify the practice.

SEED

Characteristics of the seed used affect practically every step and process involved in artificial reforestation with the southern pines. Fluctuations in the quantity of seed produced cause great and costly fluctuations in planting schedules; the area planted by one lumber company dropped from 2,200 acres in 1926–27 to 300 acres in 1927–28, and increased again to 7,000 acres in 1928–29, solely because of variations in the seed crop. The behavior of cones during seed extraction, and differences in the yields from different lots of cones, affect the cost of the seed. Since seed of the southern pines especially in demand for reforestation run fewer to the pound than most conifer seeds, and since nursery and planting costs are low in the South, anything tending to increase the cost of seed has a relatively greater effect on the final cost of planting southern pines within their natural ranges than on the final cost of so planting most other species. All nursery technic hinges on the seed's germination requirements.

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its germination percentage, the length of time it requires to germinate, its attractiveness to birds, the season of sowing that best suits its temperature requirements, and the problems of controlling weeds, insects, and damping-off (which, in their turn, are affected by season of sowing). Lastly, for successful planting the characteristics transmitted from the parent trees as to form, vigor, gum production, hardiness, and resistance to disease must be such as to fit the seedlings to the planting site and to the purposes of the plantation. Preferably, planting should not be undertaken without a thorough knowledge of the origin and quality of the seed.

Southern pine seeds, like those of most other pines, take two growing seasons to mature. Rain or frost during pollination in the spring may ruin the crop that would normally mature in the fall of the succeeding year, and adverse weather or insect attack at any time during either of the two summers or the winter intervening can destroy the cones or seed.

The male or pollen-bearing flowers of the southern pines grow in clusters between the preceding year's needles and the new bud; that is, at the base of the current year's growth. They may appear on practically all twigs throughout the crown of the flowering tree, except the most vigorous twigs at the top of the crown and on the stronger side branches. On these more vigorous twigs the female or cone flowers develop, not at the base of the new growth but at the tip of its first node.

Pine pollen is wind-blown. Pollination of slash pine takes place in late January and early February; in the Gulf States longleaf and loblolly pines are pollinated for the most part in March, and shortleaf pine about the middle of April. The time during which cone flowers are receptive to pollen is very short, and differs somewhat among individual trees of the same species. Moreover, the male and female flowers of an individual tree do not always mature simultaneously; in some instances at least, the male flowers mature first and shed most or all of their pollen before the scales of the cone flowers on the same tree open to receive it. This difference in date of maturity, together with the location of most of the female flowers in the crown, above most of the male flowers, may account for the failure of some trees to produce seed abundantly, and may also permit some cross-pollination that would not otherwise take place. Cross-pollination makes it difficult to obtain seed of known male parentage and even leads to hybridization, as of longleaf with loblolly.

During the summer, fall, and winter after pollination, the cones increase very little in size. They enlarge rapidly in their second spring, and early in the ensuing summer attain their full size. The usual dates of maturity are given in table 5, and are discussed more fully in the section on seed collection.

Estimates as to the frequency of cone crops of the southern pines cannot reliably be based on stem analyses of seedlings or saplings that appear to have come from the same seed crop; such evidence is inconclusive because of the likelihood that on any area from which stems are taken for analysis drought and fires will have wiped out practically entire crops of seedlings and, in the case of longleaf pine, because of an extended, nonuniform delay in beginning height growth and of a general failure to become dormant in winter and

thus form distinct growth rings. Systematic cone-crop reporting for the southern pine region as a whole was first undertaken in 1931. The records thus obtained cover too short an interval to permit drawing any detailed conclusions concerning seed production of the southern pines; but from earlier, though less comprehensive, records it appears that seed of each species is produced in some part of the region every year with but few exceptions, and that of the four principal species loblolly pine produces seed most frequently. Records for longleaf pine on specific areas show 2 and 3 good seed crops in consecutive years, and 5 fair to heavy crops within 10 years.

Seeds of longleaf pine are remarkable for their size, their comparatively soft and leathery seed coats, the firmness with which their wings are attached, the low temperature at which they germinate, and the quickness with which they lose their viability in warm weather. The seeds of the other southern pines have harder coats and less firmly attached wings, and in general are more like the seeds of pines native to the Northeastern or Western United States. They usually germinate less promptly than longleaf pine seeds, but keep better at natural air temperatures; they sometimes pass into a dormant state, which is, however, less marked than that characterizing the seeds of the five-needled pines of the North and West.

In size, form, and color the seeds of the southern pines are extremely variable, even within species. The seeds from any one tree, however, are similar to each other in form and color, because not only the cone but also the seed wing, the outer and inner seed coats, and even the endosperm or "meat" of the seed are invariably made up of tissue derived entirely from the female parent tree, only the embryo itself having possibly resulted from cross-pollination. The number of cotyledons or seed leaves of southern pines varies considerably even among seedlings from seeds of the same cone.

The technic of collecting, extracting, and marketing southern pine seed, and investigations dealing with treatment, storage, and source of the seed, have passed little if at all beyond the pioneer stage. There has been a gradual improvement in cone kilns, and several agencies and individuals have raised the standard of seed for their own use or for sale by cleaning it in agricultural seed mills capable of removing the empty seeds. Seed testing has been insufficiently developed and applied. Records of seed source and of the quality of the parent tree have been inadequate or wholly lacking for all but a few plantings.

COLLECTION

Because the trade in southern pine seed is comparatively undeveloped, private and State foresters concerned with forest planting in the southern pine region frequently find it necessary to collect and extract their own seed supplies.

An area's desirability for pine-seed collection depends on four things: (1) Abundance and quality of cones, (2) presence of a logging operation or of trees that can be climbed economically, (3) accessibility, and (4) hereditary qualities of the parent trees.

The first three of these considerations affect directly the cost of the seed, and hence the cost of nursery stock and of plantation

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establishment. It is obviously less expensive to collect cones from well-loaded trees and from areas near a source of labor or readily accessible by truck. The nearer to the seed-extracting plant the cones are collected, the lower are the shipping charges.

Hereditary qualities of the parent trees affect vitally the success and ultimate value of the plantation. In general it has proved unwise to use seed from one region in another region markedly different as to temperature, especially if the differences are in average summer temperature, minimum winter temperature, or annual duration of temperatures high enough to permit rapid growth (*6*, *12*, *16*). Even if no marked regional differences as to temperatures are involved, it may be unsafe to introduce a forest-tree strain in a region where the rainfall differs greatly in quantity or distribution from that of the strain's natural range. If an area must be planted with seed originating at any considerable distance, therefore, care should be taken to choose seed from a locality for which weather records [2] indicate a climate similar to that of the planting site.

It should be a fixed policy to choose as a seed source the stands and individual trees that are the best available as to form, growth rate, quality of wood, and freedom from injurious insects and disease. Although precise information is lacking as to the extent to which any of these characteristics are hereditary in the southern pines, the probability that the use of choice seed will increase considerably the thrift and productiveness of the planted stands is too great to be disregarded—particularly in view of the fact that stands now being established by planting are expected to give rise, by natural reproduction, to successive generations of commercially valuable trees. If only a part of the quantity of seed needed can be obtained from parent trees of the best quality, this part should be planted separately from the other seed used and separate records should be kept of the results obtained with the different grades. Separate records should of course be kept, also, of results with seed from different geographic sources.

Success in collecting cones depends in part on systematic scouting, which usually should be done during August. Scouting trips should be supplemented by correspondence with landowners, contractors, and other local observers. Particular care must be taken to base the estimate of a crop's abundance on actual counts of cones borne by a considerable number of representative trees.

Counts of longleaf and slash pine cones are likely to be considerably more accurate than counts of loblolly and shortleaf pine cones, because cones of the latter species are smaller. A count of cones on standing trees is particularly difficult in the case of shortleaf pine, because cones of this species remain attached to the branches for several years and the count must be restricted to the current crop.

Figures are given in table 4 for converting numbers of cones to bushels. Figure 2 shows the relative size of representative unopened cones of the four principal species.

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[2] Weather records are obtainable from the Weather Bureau, U. S. Department of Agriculture, Washington, D. C.

TABLE 4.—*Usual sizes*[1] *of unopened cones and usual numbers of cones per bushel*[2]

Species	Length of cone		Diameter of thickest part of cone		Cones per bushel	
	Average	Range	Average	Range	Average	Range
	Inches	*Inches*	*Inches*	*Inches*	*Number*	*Number*
Longleaf	6	4–10	2.0	1.6–2.7	100	86–118
Slash	3–4	2.4– 6.0	1.6	1.3–1.8	200	157–243
Loblolly	3	1.8– 4.4	1.2	.7–1.7	500	393–1,080
Shortleaf	1.8–2.0	1.1– 2.8	.8	.5–1.1	2,000	1,444–2,545

[1] Cones from vigorous young trees tend to be above average in size, and hence below average in number per bushel. The reverse is true of cones from old trees.

[2] Figures that indicate the approximate range are of averages for lots of cones. Individual cones outside the length and diameter ranges indicated are found not infrequently. Figures for length and diameter are based on measurements of samples from relatively few collections. Figures for numbers of cones per bushel are based on more ample data.

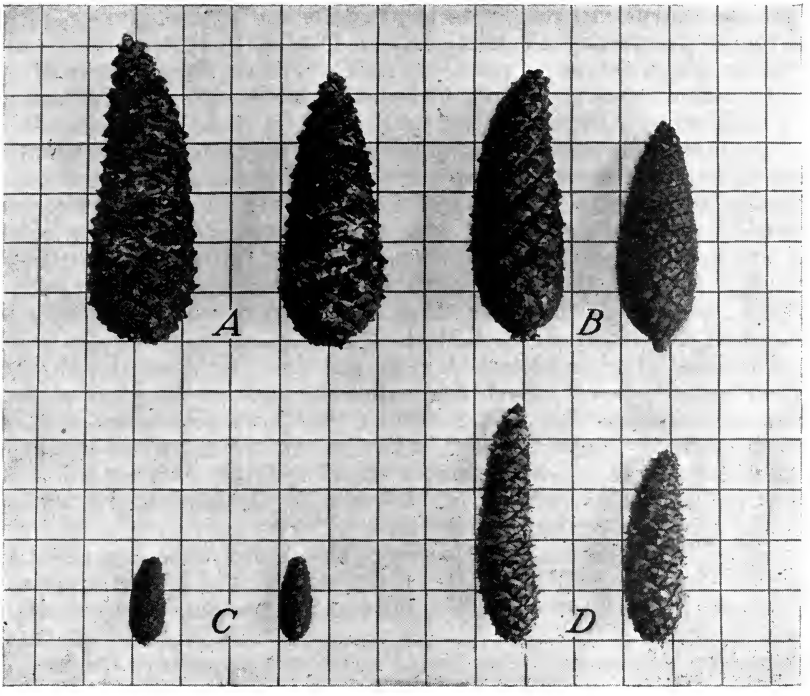

FIGURE 2.—Unopened cones: *A*, Longleaf; *B*, slash; *C*, shortleaf; *D*, loblolly pine. (Background ruled in inches.)

Table 5, based on data collected during the period 1923–30, gives for each of the four species the period within which the cones usually ripen and that within which they usually open on the trees and the period preferable for collection. Particularly notable is the early ripening and opening of the cones of slash pine.

TABLE 5.—*Usual dates of maturity and opening of cones of southern pines, and periods preferable for collecting them*

Species	Ripening	Collection	Opening on trees
Longleaf	Oct. 1–20	Oct. 1–20	Oct. 20–Nov. 10.
Slash	Sept. 1–10	Sept. 1–20	Sept. 20–30.
Loblolly	Sept. 20–Oct. 10	Oct. 1–20	Oct. 10–30.
Shortleaf	Oct. 1–20	Oct. 11–30	Nov. 1 on.

Seasonal weather variations during the period of ripening, and other weather influences, often cause considerable departures from the usual dates of maturity. In 1924, for example, unopened slash pine cones were collected near Slidell, St. Tammany Parish, La., as late as October 18, but in 1927 slash pine cones in the same locality had opened and shed all their seed by September 20. In 1927 longleaf pine cones in southern Jackson and Harrison Counties, Miss., near the Gulf coast, began to shed their seed by September 15 and had shed practically all of it early in October, whereas on a similar area in Pearl River County, 40 miles farther from the Gulf, the first longleaf pine seed was shed about October 10 and the last was not shed until November.

The figures in table 5 furnish a general guide for use in planning cone collection; the exact date on which to begin gathering the crop should be determined by observation in the field. As a rule, cones should not be collected until they have begun to turn brown. Cones of any species may ripen, open, or be collected 1 to 3 weeks before or after the periods shown in table 5. Slash pine is perhaps more likely than any of the three other species to ripen and shed its seed ahead of the time indicated by the table.

The ideal time to collect is when the first few cones in an entire stand begin to open. Such late collection insures the greatest possible ease in extraction and, since by that time the cones have lost much of their weight through drying on the trees, reduces transportation costs. It involves some risk of missing part or all of the crop. The risk is greatest in the case of slash pine, the cones of which open particularly easily and quickly and, over most of the range of the species, mature early in the season, when spells of hot, dry weather are still frequent. Collection should begin fairly early in the season if large quantities of seed are needed. Very early collection, on the other hand, adds to transportation costs and to extraction costs, because of the excessive quantity of moisture in the cones, and involves danger of difficulty or failure in extraction.[3]

In the South, no species of squirrels are known to hoard cones. Even after the heaviest seed fall, seed cannot be collected in satisfactory quantities from the ground or other flat surfaces. Collection from ponds or streams is hardly possible, unless in the case of longleaf pine; wetting combined with any rubbing or tumbling removes the wings from seeds of the other southern pines, and sound seeds without wings usually sink in water.

[3] Southern pine seed mature earlier than the cones containing them; but extraction of the seed from immature cones, that is, cones not in condition to open readily when subjected to drying, is too difficult to be practical.

Collection from felled trees is easier and cheaper than collection from standing trees. Cones of longleaf and slash pine are so heavy and so easily detached that most of them fall off when the tree top hits the ground, and need only be picked up. Collection from felled trees has the disadvantage that, even though the seed of certain individual trees proves especially adapted to a given planting site, later crops cannot be obtained from them. Felling trees for their seed alone usually does not pay, because of the stumpage value and the labor cost involved.

The equipment needed for collecting from standing trees includes light ladders, climbing irons, and pruning hooks or poles. Some workmen prefer to use only ladders for climbing second-growth trees of moderate size. Ladders are easy to obtain locally; but when climbing irons and hooks or poles are to be used, collectors sometimes find it a good plan to supply this equipment to contractors as well as to day laborers, making them financially responsible for it.

Some use has been made of a pruning pole having at one end a movable blade worked by a wire running to a lever at the other end. Less expensive and cumbersome, and ordinarily much more efficient, is a light pole 8 or 10 feet long, having bolted to one end a Y-shaped blade of ¼-inch iron, the fork of which is 2 inches deep and 1¾ inches from point to point. With this, any cone within reach can be poked, knocked, or twisted off. A modification of this pole especially adapted to the collection of loblolly cones has a hook-shaped instead of a Y-shaped blade. A thong at the handle end to go around the wrist facilitates use of the pole, and an extension may be slipped onto the handle to permit reaching cones on particularly wide-crowned trees.

Most workmen can handle longleaf, slash, and shortleaf pine cones with their bare hands, but few care to handle loblolly pine cones without leather-palmed gloves.

Whether collection is from felled timber or from standing trees, it is quicker to gather the cones in bushel or half-bushel baskets and pour them from the baskets into sacks than to gather them directly into the sacks. Cones should be sacked in either 1-bushel or 2-bushel lots, to simplify tallying the quantity obtained. Bushel sacks are easier to handle. Payment for piecework on unopened cones, and purchase of such cones, should be based on volume, not weight, because weight changes rapidly and irregularly as the cones dry. The accuracy of the measure of sacked cones can be checked at delivery by measuring the contents of a few sacks chosen at random, and checking the remaining sacks by eye as they are tallied.

All pine needles and other trash should be separated from the cones before they are sacked, preferably before they are placed in the baskets. This cleaning saves the cost of transporting waste material, makes it possible to empty cones from sacks into drying racks without further cleaning, and simplifies cleaning of the seed. Even with the best seed-cleaning equipment, bits of dried, broken needles are hard to remove.

Except when seed is very scarce, all wormy cones should be culled at the time of collection. They yield only one-third or one-half

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as much seed as sound cones; in addition, they break badly during tumbling, with the result that bits of cone scale, almost impossible to remove, become mixed with the seed.

Any company or individual collecting more than one lot of cones, even of a single species, should place on every sack before it is moved from the collecting ground a label showing unmistakably the species, place of collection, and quantity. A tag that can be removed from the outside of the sack and put in the drying rack with the cones is perhaps the most satisfactory. Labels inside the sack are useless both because they cannot be read without opening the sack and because the cones are likely to grind them to pieces.

Necessary notes on character and location of seed trees should be taken in the woods when the cones are collected, not left to memory until some more convenient time.

EXTRACTION

A bushel of unopened cones of any southern pine species weighs from 28 to 45 pounds. Of this weight 35 to 65 percent or more represents water, nearly all of which must be removed before the cones will open and free the seed. When opened, the cones occupy from two to three and one-half times the space they occupied before. Any equipment used in extracting the seed must be strong enough for the maximum weight of the cones before opening and roomy enough for their maximum volume after opening.

PRECURING

The term "precuring" covers both the storage of cones waiting their turn in drying racks or kiln and the preliminary air-drying of cones that, because of excessive moisture content or other adverse conditions, would fail to open normally if subjected at once to artificial heat. In the former, the chief purpose is to keep the cones from molding or fermenting. Precuring as a preliminary to final drying by artificial heat is needed rather frequently by longleaf cones, and somewhat less frequently by shortleaf cones. It may be needed occasionally by slash and loblolly cones. Without preliminary drying the cones may caseharden; that is, the outer surfaces may dry almost completely before the inner portions lose much moisture, with the result that the cones remain permanently closed.

FINAL DRYING

Drying at (natural) air temperature requires only relatively simple and inexpensive equipment, and involves no danger of injuring the seed by overheating. On the other hand it is slow; tends to leave many sound cones unopened; fails entirely to open the cones of such species as sand pine (*Pinus clausa* [Engelm.] Sarg.) and pond pine (*P. rigida serotina* [Mich.] Loud.); exposes the seed to birds, mice, and rats; and, for large-scale operation, requires very bulky equipment. It is often the preferable method of handling small lots of cones, is especially adapted to certain types of research, and is sometimes useful for supplementing large kiln operations.

Final drying at air temperature takes from 3 days to 3 or more months; usually, it takes at least 3 to 6 weeks. Except from well-

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matured cones of very high quality, the yield obtained by such drying is usually lower than that obtained by using artificial heat. Representative yields for various species are shown on page 23.

Drying at air temperature is carried out most effectively and efficiently indoors, with the use of movable racks or trays arranged in tiers. Drying in bins or on tight floors makes less efficient use of room space, and yields less seed per bushel of cones unless great care is exercised to keep the layers shallow and to stir the cones often.

In the South heavy dews and frequent rains make it impracticable to dry cones by spreading them outdoors in the sun on tarpaulins and covering them with other tarpaulins at night as is done in other regions. Tiers of cone trays mounted on light trucks, which could be run out when the sun shone and pushed back into a shed at night or during rains, have been used with success on one small operation in the South; but this method requires too much equipment for large operations. Extraction in well-ventilated bins under glass has been suggested, but would require expensive equipment.

Extraction by artificial heat requires more elaborate equipment and demands more skill on the part of the operator. Having the advantage of speed, in large operations it requires less outlay for building space and for racks and other bulky equipment than would be required by air drying. It usually results in more complete extraction; in the majority of cases, probably, it is essential to obtaining full yields. It involves much less danger of destruction of seed by insects, mice, and birds, because the period of exposure is shorter, the temperatures are higher, and workmen are present much of the time.

Final drying by artificial heat ordinarily takes from 12 to 72 hours. A plant requiring the latter period is inefficient. Representative yields of seed of various species are shown on page 24.

If cones are to be dried entirely at air temperature, provision should be made for abundant openings in the side walls of the drying room, free movement of air across the racks, and the admission of as much sunlight as possible. Fans can sometimes be used to good effect to force the circulation of air. In a kiln, on the other hand, if the convection type is used, there should be the fewest possible openings in side walls, but abundant provision for the escape of moisture-laden warm air at the top; if a forced-draft kiln is used, the openings must be an integral part of the particular system installed. Information concerning the most recent developments in kiln design is obtainable from the Forest Products Laboratory, United States Forest Service, Madison, Wis.

A cone-drying device that is suggested for use with southern pine species is a large horizontal drum rotated in a column of hot air. Seeds loosened from cones contained in this drum are shaken out onto an inclined screen leading to temporary storage boxes. Other devices consist in hand-moved trays or power-driven endless belts (*4*) or metal spirals (*2*), by the use of which cones are introduced into the top of a column of warm air and, as they dry, are moved downward into hotter, drier air. In Europe, a truck has been devised in which cones are partially dried on the way to the seed house by means of heat from the engine.

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TUMBLING

With most types of drying equipment, when drying has been completed it is necessary to tumble the cones vigorously to shake out the seed. This tumbling is best done in a container made of wire the mesh of which is small enough to stop unopened cones and the larger fragments of broken cones but large enough to permit the passage of seeds with wings attached. Hardware cloth of ½-inch-square mesh is good for this purpose. A tumbler of this material separates the seed from the cones in one operation.

Revolving tumblers have generally proved satisfactory. They may be round, square, or hexagonal in cross section, and either intermittent or continuous in action. An intermittent tumbler is uniform in cross section, has closed ends, and is loaded and emptied by means of a door running the full length of one side. A progressive tumbler usually tapers slightly, has no side door, and is open at both ends; the cones are fed in at the smaller end and, as the tumbler revolves, work down to the larger end and drop out. In either type, the seeds fall through the wire sides of the tumbler into a receptacle below.

DETAILS OF EXTRACTION

Throughout the three stages of extraction just described the man in charge must constantly guard against injury to the seed, loss of seed, mixture of seed of different lots, and excessive cost of the operation as a whole.

The chief sources of danger to the seed are excessive temperature and overlong exposure during final drying by artificial heat. No harmful effects from the use of artificial heat need be feared if the temperature in the extracting plant never exceeds 120° F., if good ventilation is provided, and if the seed is removed shortly after all the cones have opened. Preliminary tests indicate that seed of species having cones difficult to open, such as sand pine, pond pine, and, under certain conditions, shortleaf pine, may safely be extracted at kiln temperatures of 140° or more.

In general, a maximum temperature of 120° F. and a relative humidity of 20 to 30 percent, with free circulation of air, are recommended for final drying by artificial heat.

The results of germination tests with several lots of southern pine seed, of which some were extracted at air temperature and others under controlled conditions in a lumber kiln, are summarized in table 6. With one important exception, the differences in germination of these lots of seed were explainable by errors of sampling or variations in the completeness with which defective and empty seed were extracted from the cones. The exception is the low germination of longleaf pine seed extracted at 140° F.; seed of this species, according to the results of this and other tests, is injured by temperatures higher than 130°.

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TABLE 3.—*Average germination, in standard sand flats, of seed extracted from comparable lots of cones under different conditions of temperature and relative humidity* [1]

Species, time of collection, and State	Average germination,[2] in standard sand flat, of seed—			
	Extracted in outdoor racks at air temperature	Extracted in lumber kiln at—		
		120° F.,[2] 20% rel. hum.	120° F.,[2] 30% rel. hum.	140° F.,[2] 10% rel. hum.
	Percent	*Percent*	*Percent*	*Percent*
Longleaf pine, October 1925, Texas	83. 5	74. 7	----------	12. 4
Loblolly pine, Oct. 6–11, 1925, Louisiana	53. 5	----------	53. 4	45. 7
Loblolly pine, Oct. 19, 1925, Arkansas	59. 5	----------	53. 8	65. 4
Shortleaf pine, Oct. 19, 1925, Arkansas	64. 5	----------	65. 3	67. 6

[1] Table based on studies made by E. W. Hadley when assistant silviculturist, Southern Forest Experiment Station. Germination is in terms of all seeds sown.
[2] Temperatures practically constant.

Excessive molding or fermenting of cones not only makes them harder to open but also injures the seed and apparently decreases its ability to remain viable in storage. Cones are seldom seriously affected by mold unless they have been rained on during shipment or have been stored for a week or more in the sacks, in poorly ventilated bins, or in deep layers on the floor. If cones must be stored in sacks, the sacks should be set on end far enough apart so that the air can circulate freely about each.

The first step in avoiding loss of seed is careful selection of cones, specifically avoidance of immature or wormy cones. As a second step proper precuring to prevent casehardening is important particularly in the case of longleaf and shortleaf pine cones, and of cones of any species that are collected before turning brown. To prevent heavy losses of seed through action of birds and animals, in operations carried on at air temperature, it is recommended that all openings be carefully screened and that pests be systematically trapped and poisoned. Tumbling should be done in moderately dry weather, particularly if the cones have been dried without artificial heat; otherwise, there is danger that the cones will absorb moisture from the air and their scales close sufficiently to retain some seeds even if tumbled vigorously.

Danger of fire in cone kilns arises from the fact that the floor, cone trays, and other woodwork become extremely dry and that the hot, dry, resinous cones are highly inflammable. It is increased if poor ventilation results in accumulation of turpentine-laden vapor from trays of unopened cones recently placed in the kiln, or of dust from the tumbler or seed mill. The worst of the fire danger is avoided if heat is supplied to the kiln not from a furnace in the same building but by means of steam from a source outside the building. Prohibition of smoking, and scrupulous care with fire in general, should be sufficient additional safeguards.

Loss of seed by spilling is lessened by proper design and handling of equipment. In some extracting plants the men work in stocking feet to avoid crushing spilled seed.

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Accidental mixing of trays or lots of seed can be avoided by using good labels on all trays. Use of a distinctively colored tag or card for each species is suggested, with appropriate numbers or letters for the separate lots. All cone trays should be made of wire fine enough to hold the smallest seeds extracted; screen wire having 16 meshes to the inch is satisfactory. If coarse wire is used, seeds drop through the bottom of the tray when it is moved, or sift down into other trays in the tier, perhaps to become mixed with seed of other lots. To keep seeds from catching in cracks of the cone tray and later mixing with seed of other species it is well to bring the edges of the wire bottom of the tray up inside the tray frame and tack them at the top, instead of tacking them flat on the bottom of the frame. The cone tumbler, also, should be constructed with the fewest possible cracks or edges capable of catching seeds. In an extraction operation involving more than one lot of seed, any cones or any seeds falling out of the proper container should be discarded. These precautions against mixing seed are particularly necessary if the seed is to be certified to a purchaser as to origin or is to be used in research.

To avoid excessive cost in extracting seed, the operator must locate his extracting plant advantageously, keep his investment in equipment within reasonable limits, prevent waste of heat and power, and make efficient use of labor.

For an agency extracting seed and also maintaining a nursery it may be most advantageous to locate the extracting plant at the nursery, especially if the nursery is centrally situated in the district from which cones are to be obtained. On the other hand it may be preferable to establish the extracting plant in connection with a sawmill or pulp mill, so as to take advantage of the supply of steam. The choice of a location may be influenced also by availability of suitable buildings; the space requirement argues against using property of high rental value, or constructing new buildings when old ones will do.

If large quantities of cones are to be collected at a point far distant from the main extracting plant or nursery, the cost of setting up a temporary plant and extracting the seed at the place of collection, plus the cost of shipping the seed alone, should be weighed against the cost of shipping the cones and extracting the seed at the main plant.

Time and effort expended in handling cones give greater returns if the drying racks are above the level of the tumbler and the tumbler is well above the receptacle for empty cones, instead of all operations being carried out on the same level. If artificial heat is to be supplied by any means other than flat steam coils, the deck supporting the cone racks must be high enough to make room for the furnace, stove, or vertical steam radiators. A plant having an elevated deck for the drying racks should preferably be located on a side hill, since in that case the cones can be transferred from trucks to the drying deck without waste of effort.

In constructing a building for an extraction plant it behooves the operator to make sure that his floors are strong enough to bear the weight of undried cones in the quantity for which he is providing space. Five hundred bushels of cones collected early in the season may weigh more than 11 tons.

If all final drying is to be done at air temperature, enough trays should be provided to hold the entire season's collection of cones at one time. Even at plants where half the seed extracted is slash pine, maturing in September, and half is longleaf, maturing in the middle or final third of October, it is unwise to count on getting the slash pine cones open by air-drying alone in time to free the trays for the longleaf cones. If artificial heat is used fewer trays are necessary, even though there must be several extra sets for precuring in addition to those used in the kiln. The more efficient the kiln, the fewer the trays required.

An operator should not construct or buy an extracting plant and its accessory equipment until he is reasonably sure what quantity of cones he will be obliged to handle in the near future. In laying out the plant provisions usually should be made for expansion, which may be occasioned by bumper crops, an increased planting program, or an improved market for seed.

Once cones have been freed of needles and other trash and have arrived at the extracting plant they should never again be handled singly, but always in baskets, bags, or trays or by means of scoops or chutes.

One handling of loose cones is saved by providing extra trays of standard size into which cones can be emptied from sacks for precuring, as these trays can be transferred directly to air-drying racks or to the kiln as soon as space is available. If standard trays are not available cones should be precured on tight floors from which they can be scooped up with shovels, or in shallow bins having removable sides to permit raking the cones out into the trays in which they are to be dried.

In small extracting plants, trays should be light enough to be handled by one man even when they are full of unopened cones; otherwise two men may often be required for filling, transferring, and emptying trays when the speed requirements and quantities involved justify the efforts of only one. The trays should be of the lightest construction consistent with good wearing qualities; if not designed to hold more than a bushel apiece of unopened cones, they may be made of 1- by 3-inch cypress reinforced at the corners with flat angle irons. Galvanized screen wire of $\frac{1}{16}$-inch mesh makes good bottoms. In the racks or kiln each tray should slide on separate rails or brackets, so that it can be removed independently of other trays whenever the cones open.

Trays 3 by 4 feet are about the largest a man can handle alone. Trays 3 by 3 feet or 2 by 4 feet are easier to handle and less likely to twist out of shape when heavily loaded.

The capacity in bushels of unopened cones one layer deep in 2- by 4-foot trays varies from 1 bushel for the large longleaf cones to 0.4 bushel for the small shortleaf cones. In the 3- by 4-foot trays the capacity is 1.5 and 0.6 bushels, respectively.

For extracting longleaf pine seed the trays should be placed 10 inches apart, bottom to bottom, to allow plenty of clearance for the opened cones. Other species require less space between the trays, with a minimum of 5 or 6 inches for shortleaf pine; details of spacing must be worked out to suit the special conditions and requirements of the extracting plant concerned.

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For the most efficient extraction either at air temperature or by artificial heat, unopened cones should not lie more than one layer deep in the trays.

Any hopper or tumbler door for receiving cones should be considerably wider than the tray or other receptacle from which the cones are to be poured; if it is not, many cones will bounce out.

An intermittent tumbler of the type described on page 16 and shown in figure 3 (2½ by 2½ by 6 feet and mounted on a shaft of 2-inch iron pipe) will hold at one time the equivalent of 3 or 4 bushels of unopened cones. Considerably larger tumblers may be desirable in large extracting plants. A tumbler of the progressive type may well be 12 or 16 feet long, 3 feet square at one end and 4 feet square at the other. A progressive tumbler with this tapering form and a horizontal shaft is better than one of uniform cross section mounted on an inclined shaft, because it is free from the end-

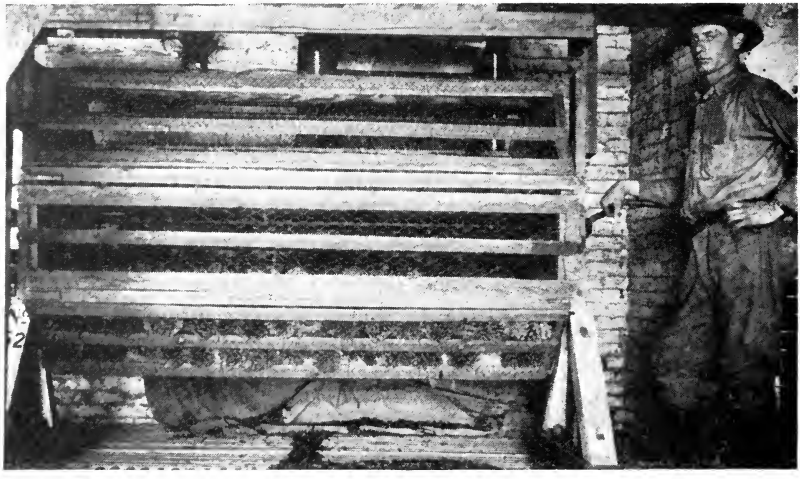

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FIGURE 3.—Intermittent tumbler for shaking seed out of opened cones. The seeds fall through grids underneath the tumbler and remain in a large, shallow box on the floor until the entire kilnful of cones has been run through the tumbler.

wise thrust of the inclined shaft. Cones are shoveled into the tumbler or run into it through a chute, at the small end. A 4-inch rim of wood keeps them from bouncing out. A few cleats across the sides may be used if needed to keep the cones from moving too rapidly to the large end, where they emerge.

Tumblers are usually turned by hand, but can be run by motor if geared down sufficiently to keep the cones from clinging to the wire because of centrifugal force.

A tray large enough to catch all the seeds dropping from the tumbler adds to convenience of operation. Where large quantities of cones are handled a better device is a wide, shallow bin built on a smooth floor under the tumbler and covered with a removable grid of narrow boards set on edge. The upper edges of these boards should be beveled to keep seeds from being lodged on them and crushed by the feet of the men operating the tumbler. Such a seed catcher is shown in figure 3; in this instance the catcher was de-

signed to hold 350 pounds of seed, all of which was shoveled out at one time.

If any considerable number of cones fails to open, these should be removed before the remainder are tumbled and should be given further treatment or discarded. A good method of sorting out unopened cones would be to slide the cones into the tumbler through a steep chute having in its floor longitudinal grids spaced widely enough to let unopened cones drop through but closely enough to stop cones that have opened half way or further. A coarse wire rack to catch the unopened cones would permit such seeds as passed between the grids to fall through into a seed tray. The grids would have to be removable and should be available in varying spacings from 0.8 or 1.0 inch for shortleaf to 2.0, 2.5, or 3.0 inches for longleaf.

CLEANING

The more fully the seed is freed of wings, empty seed, needles, and other trash the more accurate is the determination of cost, the cheaper the shipping, and the easier the sampling, testing, and sowing. As has previously been noted, seed cleaning is greatly simplified by sending to the extracting plant none but clean, sound cones.

Since the seed wing of longleaf pine is attached with remarkable firmness, seed of this species is ordinarily sold and sown without removing the wings. The greater part of the wing may be broken off, however, by running the seed through a winging machine consisting of stiff wire brushes bearing against the inside of a wire-lined cylinder, or by putting a bushel of seed at a time into a large sack and beating it sharply against a post. Care must be taken not to crack the seeds by banging them too vigorously. Partial removal of the wing not only saves shipping weight but makes possible the use of a number of mechanical devices for sowing in drills, and also reduces the probability that seed sown broadcast will be blown about by the wind.

The seed wings of all the southern pines other than longleaf are more or less easily removed either by hand rubbing or by means of a winging machine. A more efficient method is to wet the seed quickly but thoroughly, preferably with a strong jet of water, and then spread it in a wire-bottomed tray and dry rapidly, with frequent vigorous stirrings, either in the sun or under an electric fan. Wetting of seeds of these species loosens the two curved prongs with which the wing grips the seed. This treatment removes practically all the wings, and if properly carried out has no unfavorable effect on the seed.

Most of the wings and some of the other light trash can be removed by spreading the seed in a thin layer in a small cone tray or other wire-bottomed tray, holding the tray at the level of the shoulders, and then lowering it quickly about 2 feet, swinging it out of the path of the descending wings, which remain in mid-air for an instant before they begin to flutter down.

During the first 10 years of large-scale commercial collection, 1920–29, practically all southern pine seed was hand-rubbed and was either winnowed in the wind or cleaned over a fan. That these methods are far from satisfactory is shown by the high percentages of empty seeds given in table 7.

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TABLE 7.—*Average percentages of empty seed in lots cleaned commercially by means other than agricultural seed-cleaning mills*

Species	Empty seed	Basis [1]	
		Cone lots	Cutting tests
	Percent	*Number*	*Number*
Longleaf	19	15	141
Slash	24	7	35
Loblolly	39	21	163
Shortleaf	43	14	82

[1] Includes all lots of unmilled commercially cleaned seed for which records of cutting tests in the 10 years 1920–29 are on file at the Southern Forest Experiment Station.

The use of good agricultural seed mills, operated either by hand or by motor, is replacing cruder methods of cleaning southern pine seed, to the great improvement of the seed. These mills remove impurities, if need be sort or grade the seed by means of oscillating screens of various degrees of coarseness, and winnow by means of an air blast, usually vertical, from a fan built into the mill. They dispose of practically all empty seed with a negligible loss of sound seed. One type at least is capable of cleaning longleaf seed with wings attached. Such mills are essential to efficiency in both commercial and investigative work involving any considerable quantities of seed. They are available in various sizes at low cost.

Where such mills are not available, seed can be given its final cleaning by pouring it from box to box in a strong wind, or by pouring it down a steeply sloping wire screen placed over an upward-tilted electric fan. When the fan is used, proper adjustment of its speed and of its distance from the screen makes possible the removal of some of the empty seed. Seed of southern pines other than longleaf can be freed of empties by immersion in water. Once they are thoroughly wet, most of the sound seed will sink and most of the empty ones will float. In a sample of loblolly pine seed studied, a cutting test made before immersion showed 33.4 percent of empty seed. After immersion, cutting tests showed 87.8 percent of empty seed in the portion that floated, and only 3.2 percent in the portion that sank.[4]

In buying seed, inquiry should always be made as to the method of cleaning, and assurance obtained that the process has not damaged the seed.

The price per pound of southern pine seed is likely to be higher the better the cleaning, both because of extra labor involved and because each bushel of cones yields a smaller weight of well cleaned than of poorly cleaned seed. The number of seeds per pound is smaller the better the cleaning, because it takes fewer full seeds than empty ones to make a pound. Even so, well-cleaned seed is likely to cost less per 1,000 trees produced.

[4] Baldwin (*1*), working with red spruce (*Picea rubra* Link.), obtained separation better than this by using absolute ethyl alcohol, but at the cost of some decrease in the power of the seed to remain viable in storage.

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YIELD PER BUSHEL OF CONES

The yield of clean seed per bushel of unopened cones varies according to species, cone quality, method of drying, quantity of seed lost during extraction, percentage of empty seed, and method of cleaning. With so many factors involved, average figures for yields provide no definite indication of cone requirements. Table 8 gives figures for representative yields of seed, under normal conditions, per bushel of unopened cones. These figures are for seed cleaned in the wind or with an electric fan, not in modern seed mills. Table 9 gives numbers of seed per pound for such unmilled seed, for which percentages of empty seed coats are shown in table 7. Milling, by eliminating the empty seed, reduces the yield of seed per bushel of unopened cones, as given in table 8, by approximately 10 to 30 percent.[5] Even for cones of good quality, this reduction frequently brings the yield somewhat below the empirical figure commonly quoted, 1 pound per bushel. With cones of inferior quality the yield is often much below that figure.

A comparison between rates of drying at air temperature and by artificial heat, and between quantities of seed yielded, is given in table 10.

TABLE 8.—*Representative yields of clean seed per bushel of unopened cones dried at air temperature and by artificial heat*[1]

Species	Dried at air temperature	Dried by artificial heat	Species	Dried at air temperature	Dried by artificial heat
	Pounds	*Pounds*		*Pounds*	*Pounds*
Longleaf	1.00	1.45	Loblolly	0.76	----------
	1.00	1.65		.81	1.16
	1.14	----------		.97	1.58
Slash	.87	----------		1.00	1.62
	1.00	----------		1.15	----------
	1.16	----------		1.61	----------
	1.43	----------	Shortleaf	.83	----------
				1.65	1.65

[1] Table based on all records available to the Southern Forest Experiment Station except those of yields rendered abnormal by adverse weather, premature collection, improper extraction, or abnormal insect damage. Seed was winnowed in wind or over electric fan, not in agricultural seed mill with oscillating screens and vertical air blast.

TABLE 9.—*Usual average numbers and extreme observed numbers of seeds of Southern pine per pound in samples of seed commercially cleaned*[1]

Species[2]	Usual average	Minimum	Maximum
	Number	*Number*	*Number*
Longleaf[3]	5,200	4,010	8,000
Slash	15,500	13,470	19,660
Loblolly	21,300	17,241	29,264
Shortleaf	[4] 69,200	41,614	84,985

[1] Table based on all records available to the Southern Forest Experiment Station of seed cleaned otherwise than with an agricultural seed mill with oscillating screens and vertical air blast. Samples measured were 100 percent pure but containing varying percentages of empty seed; see table 7. "Usual average" is based on inspection of an array, and checked against an arithmetic mean of the same data. "Minimum" and "maximum" are drawn from all samples observed by the station, exclusive of samples from strikingly abnormal lots of cones.

[2] For less important species, records for single samples, or for 3 or 4 samples at most, indicate the following numbers of seeds per pound: Sonderegger pine (longleaf-loblolly hybrid), 13,400; pond pine, 56,000; sand pine, 74,400; and spruce pine (*Pinus glabra* Walter), 77,500.

[3] Seed with wings attached.

[4] This figure may be unreasonably high, because of high percentage of empty seed in some samples (table 7).

[5] On the basis of 5 years' commercial collection, A. D. Read gives the following figures for average yields of kiln-extracted milled seed per bushel of unopened cones: Longleaf, 0.75 pound; slash, loblolly, and shortleaf, 0.90 pound.

TABLE 10.—*Rates of drying and seed yields, for cones of 1925 crop, at air temperature and by artificial heat* [1]

Species, time and place of collection, and method of drying	Period required for extraction [2]		Yield of seed per bushel of cones	
			Uncleaned	Commercially cleaned [3]
	Days	*Hours*	*Pounds*	*Pounds*
Longleaf pine, October, Texas, kiln-dried [4]		22	1.45	1.45
Loblolly pine, Oct. 6–11, Louisiana:				
Air-dried	15		1.25	.97
Kiln-dried		22	1.51	1.16
Loblolly pine, Oct. 19, Arkansas:				
Air-dried	7		1.96	1.62
Kiln-dried		22	1.96	1.58
Shortleaf pine, Oct. 19, Arkansas:				
Air-dried	7		2.00	1.65
Kiln-dried		22	1.82	1.65

[1] Table based on studies made by E. W. Hadley when assistant silviculturist, Southern Forest Experiment Station.

[2] Kiln-dried cones were kept at 120° F., with constant relative humidity of 30 percent, except the longleaf lot, which had 20 percent relative humidity.

[3] Over electric fan, not in seed mill.

[4] Records of seed of this lot extracted at air temperature are unavailable because part of the seed so treated was destroyed by birds.

There is some evidence (*35*) that the yield of sound seed per bushel of cones is less when the cone crop is light than when it is heavy. Experience and general observation suggest, also, that the yield per bushel of cones gathered from isolated trees or in very open stands is below average, owing to relative incompleteness of pollination.

STORAGE

An effective method of storing seed for at least 1 or 2 years is of the utmost importance as insurance against failure of seed crops. It also facilitates obtaining seed of suitable heredity for planting on given areas; may reduce the cost of artificial reforestation during periods when crops are light and collection expensive; and may prevent total loss of seed not used in the first season following collection.

Seed of southern pines, particularly longleaf pine, has been noted to deteriorate rapidly in storage. This rapid spoiling may have resulted partly from inherent characteristics of the seed, partly from climatic conditions, and partly from unsuitability of the storage methods used. Cold storage, according to the results of recent tests, keeps all species of southern pine seed in good condition for at least 1 or 2 years.

A further important consideration in seed storage is its effect upon promptness and completeness of germination. It has, however, been very difficult to obtain conclusive data on this point because of the wide variation that often occurs in tests of comparable seed samples. Figure 4 shows differences in promptness of germination between fresh seed and seed in cold storage for 1 and 2 years. The significant fact is that the differences here shown are less than differences that often occur between comparable samples of fresh seed.

The most convincing data obtained in this study indicate that the temperature at which seed is stored has a considerable influence on

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subsequent germinability. In one instance two lots of longleaf pine seed that had been stored in paper sacks for 1 year yielded 60 percent germination for the one lot that had been stored at 32° F. and 26 percent for the second, stored at ordinary room temperature. Check tests of fresh seed from these two lots each yielded 55.6 percent. In these tests the only important variable was temperature, and the very decided indication in favor of a freezing temperature for seed storage was supported by other tests of longleaf, slash, and shortleaf pine in which seed was stored in sealed or

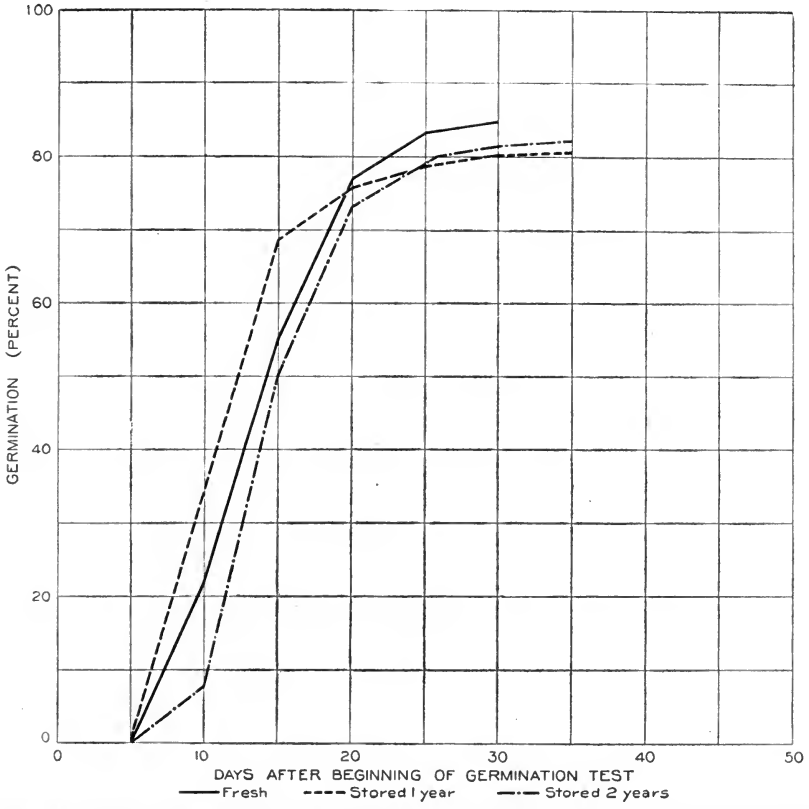

FIGURE 4.—Rates of germination of longleaf pine seed when fresh and after storage in sealed glass jars at 25° to 35° F. for 1 and 2 years, respectively. Percentages based on total numbers of seed with kernels.

closed containers. In every case seed stored for 1 year at room temperature had a notably lower germination than either the seed in cold storage or the check sample of fresh seed. In two 2-year tests of longleaf pine seed in sealed or covered containers, germination of seed in cold storage compared very satisfactorily with the check samples, whereas the two samples of the same seed stored at room temperature completely failed to germinate.

So far as these few tests can be relied upon, they indicate that slash pine seed fares as well at a temperature around 40° F. as longleaf and shortleaf seed do at freezing temperature.

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In all of the tests made, the tendency of several methods of storage to give very different results with different groups of the same species indicates that some unknown factor—such, perhaps, as moisture content of the seed when it is placed in storage—has a marked effect on keeping quality. Coile (7) has shown that in sealed glass tubes at natural air temperatures slash pine seed keeps better if its moisture content is low. For the present, cold storage is the only method recommended.

Every container of seed placed in storage should be labeled with particular care, one tag being placed on the outside of the receptacle and a duplicate inside.

TESTING

Intelligent use of seed depends upon knowledge of its identity, purity (i. e., freedom from foreign matter and dwarfed, malformed, broken, or weeviled seed), and germinative ability, and of the number of seeds per unit of weight.

The species of a sample of southern pine seed can usually, but not always, be determined by comparing the sample with others the species of which is known. To be certain as to place and date of collection, and to be certain in all instances as to species, the nurseryman must supervise the collection of his seed supplies or buy from reliable dealers only, and must exercise care in regard to all seed records and labels. To determine purity requires only simple analysis and weighing, and to determine number of seeds per unit of weight requires only simple weighing and counting. Determining germinative power is a more complicated process.

PURITY

To determine the purity of a lot of seed, a representative sample is weighed and the apparently sound seeds in it are separated out and weighed. The weight of the apparently sound seeds as a percentage of the gross weight of the sample is used as the purity percentage of the lot. This percentage times the weight of the lot, times the number of seeds per unit of weight, gives the number of seeds available for sowing.

The separation of apparently sound seeds from other seeds and trash for this purpose does not involve removing wings that have remained attached to seed.

For determining purity percentage it is best to take 5 or 10 random samples. Suitable weights for individual samples are: Longleaf pine, 4 ounces; slash pine, 2 ounces; and loblolly and shortleaf pine, 1 ounce. The separation can be made most easily by spreading the seed in a thin layer on a sheet of white paper and pulling away individual seeds with one finger. The balances used to weigh the seed must be sufficiently sensitive and accurate so that instrumental errors will not obscure differences in purity between samples.

NUMBER OF SEEDS PER UNIT OF WEIGHT

The simplest way to determine number of seeds per pound is to count out a few 1,000-seed lots from the clean seed. A quick way to do this without sacrificing accuracy is to spread the seeds in a single layer on one-half of a sheet of white paper, and then, with

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one finger, pull them onto the other half in groups of 10. The accuracy of the count of each group can be checked at a glance. Ten groups of 10 seeds each can then be swept aside onto another sheet in a compact pile, until there are 10 piles of 100 seeds each.

One thousand seeds from each sample of the sizes specified in the foregoing should form a sufficient basis for determining the number of seeds per pound. Weight per 1,000 seeds in grams can readily be converted into number of seeds per pound by dividing, by it, the number 453,592, since 1 pound equals 0.453592+ kg.

CUTTING AND HAMMER TESTS

The potential germination of fresh seed can be roughly determined through either a cutting test or a hammer test.

In the cutting test seeds are cut open with a sharp knife and the kernels examined. The kernel of a sound seed is firm and whitish. For a simple cutting test intended only to afford a rough guide to density of sowing, 5 samples of 100 seeds each from each homogeneous lot or shipment may be adequate. In more elaborate cutting tests, particularly in connection with studies of germination, it is suggested that use be made of a 250-seed sample divided into 10 equal parts. (The reasons for using this form of sample are discussed in connection with the standard sand-flat germination test.)

In the hammer test, seeds are laid one by one on an anvil and hit with a hammer. The hammer smashes empty seeds, but crushes sound ones into oily white spots studded with bits of brown seed coat. The hammer test consumes much less time than the cutting test.

It is practically useless to apply either cutting tests or hammer tests to stored seed. Even when applied to fresh seed, these tests fail to show in full the percentage of seeds that will not germinate. If estimates of quantity of seed needed for sowing are based on cutting tests only, a moderate to heavy reduction must be made in the expected germination percentage as indicated by the test. This reduction must be based on experience with the species and in the nursery in which the seed is to be sown.

GERMINATION TESTS

Actual germination tests of representative samples are a better basis than cutting or hammer tests for judging the quality of fresh seed, and furnish the only acceptable basis for judging the quality of stored seed of the southern pines. They are essential to investigations of many different kinds, for example, studies of the effectiveness of very young or very old trees as seed producers and studies to determine what temperatures and humidities should be used in extracting seed by artificial heat.

STANDARD SAND-FLAT TEST

A standard sand-flat germination test particularly adapted to southern pines, although not ideal, gives comparatively consistent results and is relatively simple and inexpensive. When conducted strictly according to directions, and with seed pretreated as described on page 33, it should be of practical value to seed dealers and nursery operators alike.

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In this test 25 seeds are sown in each of 10 drills. Records are kept separately for each drill. The flats are examined daily, and germinating seeds are pulled as soon as they break through the sand or make conspicuous humps in it.

The flats containing the sand are 10½ by 10½ by 3½ inches inside. The sides are made of 1-inch pine strips. The bottoms are either of tongue-and-groove ½-inch pine flooring or of 1- by 12-inch pine.

Before being put into the flat, the sand is uniformly moistened by the addition of water equivalent to 15 percent of its dry weight. The sand is packed in the corners, to avoid later settling, but is not settled or packed elsewhere except so far as this is unavoidable.

The seeds to be sown are drawn from the entire sample by mixing the sample thoroughly, heaping it in a broad cone-shaped pile, flattening the pile, halving or quartering it, remixing a half or a quarter, and repeating until the final sample contains slightly more than 250 seeds. From this sample 250 unbroken, apparently normal seeds are taken at random for sowing. The wings of longleaf pine seeds must be removed, to conserve space in the flats.

The drills are slightly more than one-eighth inch deep. They are made with a scraper of which the ends rest on the edges of the flat and the edge projects down into the moist sand.

A device used in preparing the flat is a trough or tray, three-fourths by 10¼ inches and three-fourths inch deep, of galvanized wire having 16 meshes to the inch. The flat is set up with 10 such trays just under the surface of the sand. The drills in which the seed is to be sown are made directly over the centers of the trays. When germination is complete and it is desired to make a cutting test of the ungerminated seeds, the seeds remaining in each drill are lifted simultaneously simply by lifting the tray, and freed of sand by dipping the lower portion of the tray into a pail of water and gently shaking the tray. Trays can be cut and folded at the rate of 50 to 80 an hour. They ordinarily last for 2 or 3 tests of 2 months each. Their use reduces by about three-quarters the time required to lift the seed.

In sowing the seed, use is made of a drill seeder (fig. 5) of galvanized iron, fitted to the top of the flat. A slit 10¼ inches long, near one edge, opens downward into one drill. Other parts of the seeder cover adjacent drills, and the upturned section at the opposite edge prevents loss of seeds. Successive samples of 25 seeds each can be counted out on the seeder, spaced evenly, and, by means of a straightedge, pushed through the slit into the drills far more rapidly and accurately than would be possible by hand alone.

The seeds are covered with dry sand to a depth of one-eighth inch from their centers; greater depth has been found to reduce germination.

After the sowing, the flats are watered with a small fine-spray watering can, and set in rows on laboratory tables in a room the temperature of which ranges between about 70° and 90° F. The watering is repeated as often as necessary, usually daily or every other day, and the flats are rearranged systematically each day to equalize their exposure to light and heat.

Daily individual and cumulative records of germination for each sand flat are made on a suitable form. If there are 25 seeds per

drill, each germinated seed counts 4 percent. Time is recorded from date of start, instead of by day of month. The sum of 10 drills divided by 10 gives the average germination percentage for the entire flat. The test is usually continued until new seedlings have ceased to appear at the surface.

TESTS IN MEDIA OTHER THAN SAND

Several germinating media other than sand have been tried by the Southern Forest Experiment Station and its cooperators. One of these is acid peat moss, known also as "florists' peat." This is used in the form of a mat, made by compressing moist moss upon a mold. The mold is made by tacking several triangular strips of wood to a smooth board and arranging around the series of strips a border of wire three-fourths inch high to hold the peat in place. To keep the wire from bulging, while the peat is being packed in place the

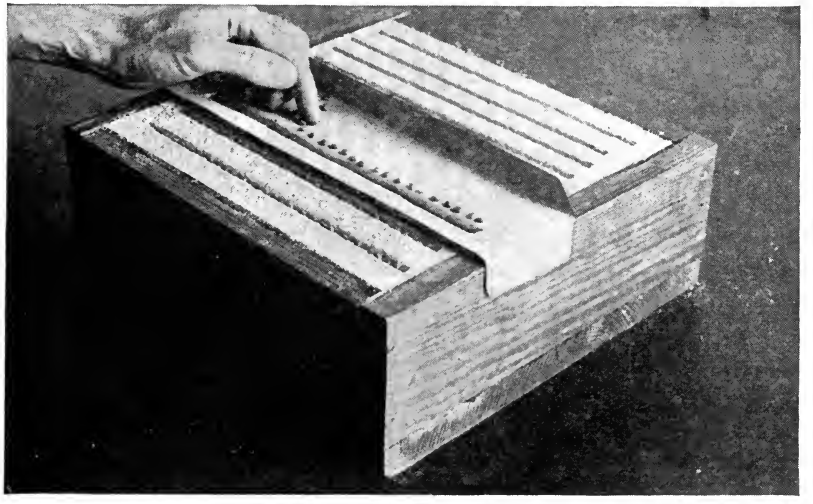

FIGURE 5.—Sowing seed in sand flat by means of the drill seeder.

wire is surrounded with a wooden frame. When the mat has been compressed as tightly as possible with the hands, mat, mold, and frame are inverted as a unit. First the mold is gently lifted off, and then the frame is removed from the mat, which remains supported by the wire border and bears on its upper surface a series of grooves impressed by the mold (fig. 6). The seeds are set up usually at the rate of 25 to each of 10 grooves. The mat is placed in a square glass baking dish of suitable size and depth and covered with glass. Enough water is poured into the dish so that after the peat has absorbed all it will take up, a shallow layer will remain free in the bottom. This medium keeps the seed well supplied with water, and offers somewhat less encouragement to mold than do most media on which the seeds are exposed directly to the air. The peat appears to stimulate the germination of seed of certain species, particularly slash pine. Exposing the seed to low temperatures as a preliminary to testing is particularly easy in connection with the peat-mat test; all that is necessary is to place the mat, with the seed on it, in a suitable refrigerator. The peat mat has the further advantages that it

requires much less space than the standard sand flat, weighs less, and does not contain any grit. At the present stage of development of its use, it gives less uniform results with some classes of seed than does the sand flat.

Germinating media that have been tried with less success are blotters or other absorbent papers used in various germinating chambers, including adaptations of the Jacobsen apparatus. These media are less easy to maintain at the proper moisture content than either sand or peat, and are more likely to become covered with mold. Several

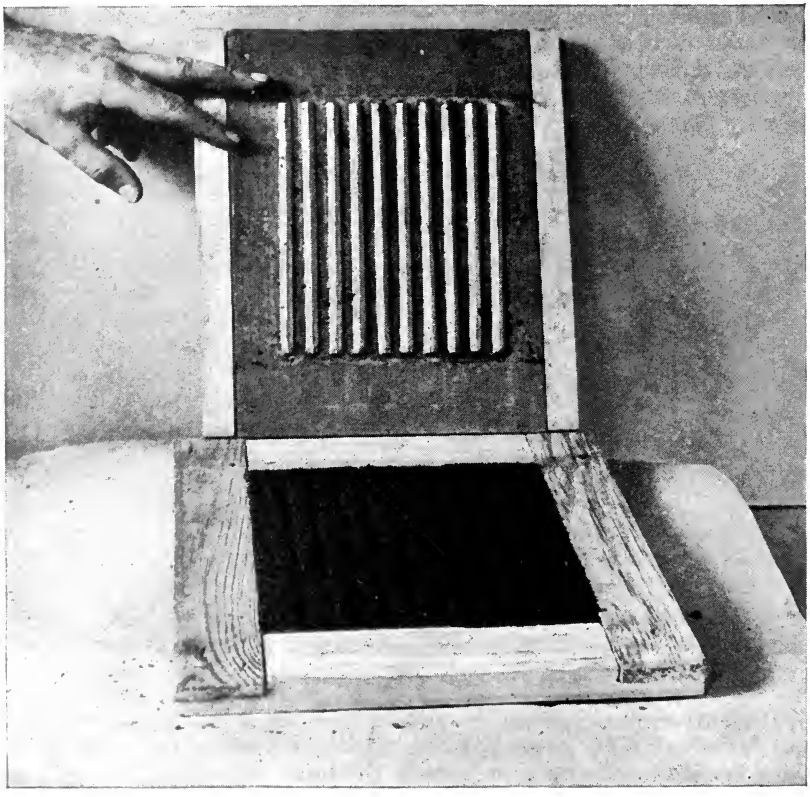

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FIGURE 6.—Removing the mold from the peat mat, which is still enclosed in the wooden frame.

of the species of mold particularly annoying in germination tests thrive upon paper itself.

A few tests of southern pine seed have been made in sand mixed with garden soil or other loam and in loam alone. Samples tested in this manner have shown germination percentages strikingly lower than those of samples from the same original lots tested in pure quartz sand. It is thought that damping-off fungi in the loam may have killed many of the seeds.

The most exacting standards of technic are necessary to obtain reliable results in seed testing. Unless germinated seeds are pulled and discarded when their germination is recorded, errors result

from their death and decay, or they become confused with more recently germinated seeds. The use of odd or irregular numbers of seeds in testing increases the likelihood of error, because such numbers are confusing and because they increase greatly the difficulty of computations and decrease the applicability of some desirable statistical methods.

At the end of a test all ungerminated seeds should be removed from the testing medium, cut with a sharp knife, and tallied as sound, spoiled, or empty. The total of the seeds tallied from day to day as germinated should be checked against the total number of seeds planted less the total number of ungerminated seeds lifted at the end of the test. Recording the number of empty seeds makes it possible to compute average germination, at any stage of the test, on the basis of all seeds with kernels (see next paragraph). The presence of a great number of ungerminated sound seeds at the end of the test indicates either that the test has not been run long enough or that the proper germination or pretreatment technic has not been used.

METHODS OF EXPRESSING AND ANALYZING RESULTS

The final germination percentage and the period required to attain it, or a curve showing the course of germination by 5- or 10-day intervals, is usually adequate as a statement of the results of a routine germination test. In tests to determine the quantity of seed to purchase or sow, final and intermediate percentages should be based on the total number of seeds tested. In tests to determine the effect of extraction or storage methods or special treatments to hasten germination, percentages based on total numbers of seeds with kernels are preferable.

The reliability of purity percentages, germination percentages, and seed weights may be estimated and expressed by computing the standard deviation of subdivisions of a single test, such as the 5 or 10 random samples suggested under Purity or the 10 drills of 25 seeds each used in the standard sand-flat test. Purity percentage, germination percentage, or weight as indicated by a series of tests may be expected not to differ (by chance) from the corresponding actual mean of the entire lot of seed by more than three times the standard deviation of the mean. The difference between the means of tests of two different lots of seed is ordinarily considered significant if it is three or more times the standard deviation of the difference.[6]

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[6] The formulae for the standard deviation of the individuals and the standard deviation of the mean, respectively, are

$$\sigma = \sqrt{\frac{\Sigma d^2}{N-1}}$$

$$\sigma \text{ mean} = \frac{\sigma}{\sqrt{N}}$$

The formula for the standard deviation of the difference between two means, M_1 and M_2, is

$$\sigma \text{ difference} = \sqrt{\frac{\sigma_1^2}{N_1} + \frac{\sigma_2^2}{N_2}}$$

In these formulae,

N = number of observations, e. g., the number of drills for which germination percentages are recorded separately or of random samples for which purity percentages or weights are recorded separately.

d = difference between the value of any one observation and the value of the arithmetic mean of all observations.

Σ = summation.

σ = standard deviation of the individual observations.

σ mean = standard deviation of the mean.

σ difference = standard deviation of the difference between two means.

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Details of methods of testing the reliability of results of tests such as those here referred to are given by Collins (*8*), Gevorkiantz (*14*), and Youden (*40*), and in standard works on statistical methods.

Statistical analysis is a useful tool in research on forest-tree seed, but should not be attempted without an understanding of its limitations.

TENDENCIES INDICATED BY RESULTS

Among the tendencies noted as an outcome of the germination tests perhaps the most distinct is a tendency for both rapidity and completeness of germination to vary directly with size of seed. Seeds of longleaf, which are larger than those of any other of the four principal species, usually show the most rapid and complete germination, when fresh. They deteriorate more rapidly in storage than seeds of the other species, however, unless held at temperatures only slightly above freezing. Slash pine seeds come next to longleaf in rapidity and completeness of germination under the best conditions, but tend to become dormant when stored in the South at room temperature either for a full year or over a winter only. In many instances slash pine seed held over winter in unheated nursery seedhouses has germinated more promptly and completely than samples drawn from the same lots and held for a while in a heated office prior to testing for germination, and it has been demonstrated that slash pine germinates promptly and well after cold, moist stratification. Slash pine seed sometimes retains its viability for 2 or 3 years even without cold storage. Occasional samples of shortleaf pine seed approach the record for rapidity and completeness of germination set by longleaf seed of good quality.

In germination tests of southern pine seed it is unnecessary and possibly undesirable to maintain uniform temperatures. Longleaf pine seed germinates at temperatures very little above freezing (*3*, *15*, *35*). Germination of seed of the other species has apparently been delayed by temperatures below 55° and prevented by temperatures a little below 50°. Seed of all four species has been killed in the middle of the test by temperatures in excess of 120°. In germination tests started at intervals of 1 month throughout the year, longleaf pine seed from the same lot showed a sudden falling off of germination in June, minimum germination in July or August, and a gradual recovery in power to germinate during the fall, apparently in part because of changes in average temperature from season to season.

The relation of moisture content of the medium to the rapidity and completeness of germination has not been clearly shown. It has been noted, however, that permitting the moisture content to decrease for 2 or 3 days toward the end of a sand-flat test, and then bringing it approximately to the 15 percent at which the sand flats were originally set up, sometimes increases total germination by stimulating germination in a few seeds that would otherwise have remained dormant at the end of the test. Results of experiments in which seed was soaked with various disinfectants (and check lots were soaked with water) as a preliminary to germination tests

indicate that soaking hastens germination, although it does not necessarily increase germination percentage.

Mold causes relatively little trouble in germination tests run in sand, but on most other media it is always at least an annoyance. Heavy mold growth is sometimes associated with complete failure to germinate, particularly in the case of seed the germinative energy of which has been reduced by storage, especially longleaf pine seed. Usually the conspicuous mold development is on seeds that are already dead or nearly so; but some fungi, mainly those which do not make a very conspicuous external growth, are able to kill seed before it starts to sprout and may interfere to a considerable extent in tests on media containing organic matter (*23a*). Efforts to control mold by rinsing southern pine seeds in formalin solution or by coating them with bordeaux mixture or colloidal sulphur have not fully succeeded and in many instances have given no control whatever. The organic mercury compounds have not been tested so thoroughly as the compounds just referred to, because they appeared to reduce germination and to cause development of stubby radicles incapable of elongation after the first day or two.

TREATMENT BEFORE TESTING OR SOWING

Fresh seed of loblolly and shortleaf pine, or seed of these two species and slash pine kept for a year or more by means other than cold storage, often fails to germinate quickly and completely. Even fresh seed of slash pine sometimes germinates tardily and in unsatisfactory percentage. If this occurs in the laboratory, it decreases the value and increases the expense of germination tests. If it occurs in the nursery, it increases the cost of seed and labor per 1,000 trees and lowers the quality and uniformity of the planting stock. Obviously, therefore, it is desirable that such seed be subjected to some treatment conducive to prompt and complete germination.

Such a treatment, developed at the Boyce Thompson Institute for Plant Research (*3*), consists in mixing the seed with moist acid peat, or arranging thin layers of seed in alternation with layers of moist peat, and keeping seed and peat at temperatures of from 32° to 40° F. for a month or 6 weeks. Actual mixing of the seeds with the peat can be prevented by placing them between folds of cheesecloth. It is well to place in each tray or in each cheesecloth layer just enough seed for a definite area of seed bed. The seed and peat can be put up in shallow wire trays, and stored for refrigeration either in a commercial cold-storage plant or elsewhere. The seed should be inspected at intervals to make sure of its remaining moist, and should be stirred, if the trays are more than 3 inches deep, to insure proper aeration.

Table 11 gives the results of tests made by this method with seed of southern pine species at the Boyce Thompson Institute and the Southern Forest Experiment Station, and by the Brown Co., Berlin, N. H., and brings out the great increase in rapidity and completeness of germination that ordinarily results from the treatment. Figure

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7 shows the course of germination of samples of southern pine seed tested with and without pretreatment in acid peat.

TABLE 11.—*Germination rat[illegible]d percentages of southern pine seed pretreated by stratification in moist acid peat at low temperatures, and those of comparable seed not so treated*

History of pretreated seed		Final germination		Total germination period		Agency [1]
Stratification period	Temperature	Pretreated	Untreated	Pretreated	Untreated	
	°C	*Percent*	*Percent*	*Number*	*Number*	
FRESH LONGLEAF SEED						
30 days	5	77.0	75.0	26	40	B. T. I.
36 days	3	72.0	55.6	40	40	S. S.
36 days	3	72.0	65.6	35	40	Do.
30 days	5–7	70.0	51.0	20	45	B. Co.
FRESH SLASH SEED						
66 days	8	95.0	79.0	15	60	B. Co.
36 days	3	93.2	58.8	25	50	S. S.
60 days	5	82.0	3.0	20	45	B. T. I.
60 days	5	78.0	37.0	20	100	Do.
FRESH LOBLOLLY SEED						
60 days	5	84.0	41.0	24	100	B. T. I.
36 days	3	68.0	12.4	40	50	S. S.
71 days	8	60.8	56.0	15	60	B. Co.
60 days	5	56.0	2.0	20	45	B. T. I.
YEAR-OLD LOBLOLLY SEED						
60 days	5	70.0	2.5	20	42	B. T. I.
71 days	8	68.0	64.2	15	60	B. Co.
35 days	0–5	60.4	58.4	50	98	S. S.
FRESH SHORTLEAF SEED						
36 days	3	98.0	74.0	20	50	S. S.
36 days	3	94.0	76.4	25	50	Do.
60 days	5	84.0	57.0	18	90	B. T. I.
YEAR-OLD SHORTLEAF SEED						
30 days	5	82.0	39.5	28	45	B. T. I.
58 days	8	81.2	88.8	30	60	B. Co.

[1] B. T. I.=Boyce Thompson Institute, data taken from (*3*); S. S.=Southern Forest Experiment Station; B. Co.=Brown Co.

COSTS AND MARKETS

The labor required to collect cones of the southern pines varies from about one-fifth man-hour per bushel of longleaf pine cones collected from felled trees in a good seed year to about 6 to 10 man-hours per bushel of shortleaf pine cones gathered by climbing in a year of poor seed production. An extracting plant with a capacity of 300 bushels of cones every 24 hours can be operated by 2 to 4 men; a less efficient plant with a capacity of less than 100 bushels every 3

days may require the same number. As a result of such variations, the cost per pound of cleaned seed ranges from $1 to $6 or more. Organizations collecting their own seed can sometimes get it for less; longleaf pine seed delivered at the nursery of the company collecting and extracting it has cost as little as 26 cents per pound.

Because of greater difficulty of collection or extraction, or greater uncertainty of demand, seed of pond, sand, or spruce pine usually costs more than that of any of the four principal species.

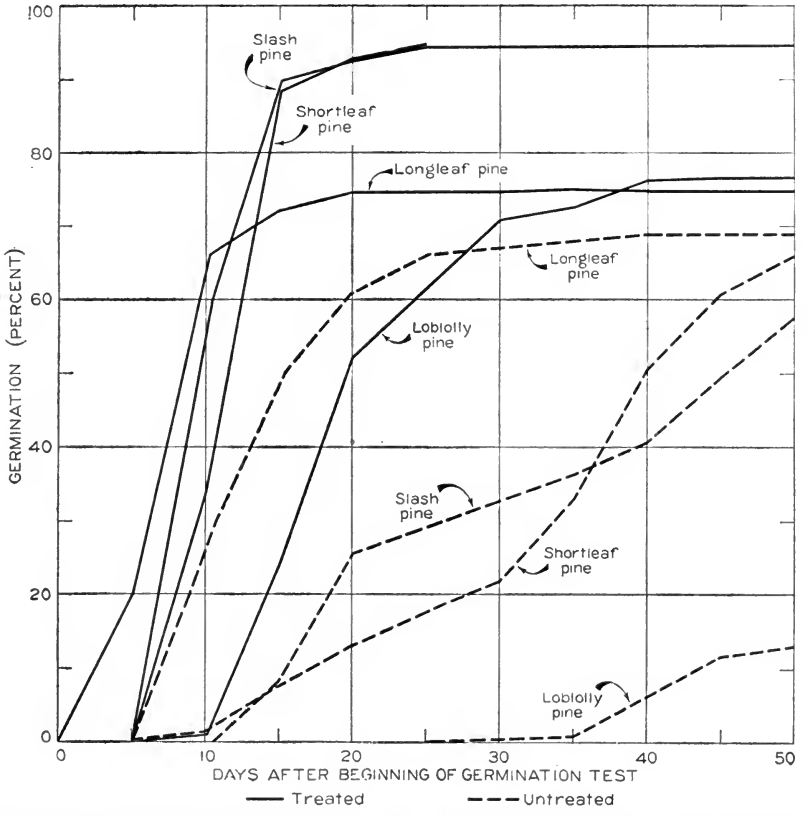

FIGURE 7.—Rates and completeness of germination of southern pine seed pretreated by stratifying for 1 month in moist acid peat at approximately 38° F., and of comparable seed not so pretreated.

On the basis of acreage planted and of average germination percentages it is estimated that the domestic consumption of southern pine seed in the decade 1923–32 may have totaled 34,000 pounds. Exports amount to several tons each year.

RECORDS

Tree seeds are not worth much unless accompanied by a record showing when and where they were collected and to what treatment they have been subjected, especially during extraction and storage. For seed to be used in research a much more complete record is often

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needed, indicating the character of the parent tree and of the soil on which it grew.

An administrative organization using from 1 to 20 or 30 large lots of seed each year can keep its seed records most simply and easily by numbering each lot serially as received, noting species, source, date of collection, method of extraction, method of storage, total quantity, and use and final destination of each of the various portions into which the lot is divided. Purity percentage, germination percentage, and price per pound should be included in the record. The record should be kept systematically in a substantial bound book of ledger form. The number given to each seed lot will become a part of the nursery record and the plantation record.

THE NURSERY

General principles and practices common to most southern pine nurseries are discussed in this bulletin on the basis of data from four nurseries maintained by the Southern Forest Experiment Station in Mississippi, Louisiana, and Florida between 1923 and 1933, from a number of minor tests carried out by the station in the nurseries of cooperating lumber companies, and from systematic surveys by the station of 19 different experimental and commercial nurseries in 10 States. The details of nursery practice must be worked out on the ground for each individual nursery.

LOCATION AND SITE

It is important that the location of a forest-tree nursery be such as to permit easy and inexpensive transportation of planting stock to the area or areas where it is to be used. It is important also that a reasonably abundant supply of labor be available near the nursery. In the South it is usually possible by locating the nursery in or near a small town to obtain satisfactory labor without the necessity of providing living quarters or transportation for workmen and without incurring unduly high taxes or rents.

The importance of an adequate supply of water cannot be too strongly emphasized. Tree seedlings growing in dense stands require very large quantities of water in the top 6 or 8 inches of soil. If rainfall is poorly distributed, or if it totals much less than 5 inches during any month between April and September, it must be supplemented by artificial watering. To apply the equivalent of 1 inch of rain to an area of 1 acre requires 27,154 gallons of water. The commonest source of supply in the South is a deep well. A few nurseries use city water. An adequate supply can sometimes be assured by damming a small creek, if the flow is fairly constant throughout the year. Prospective water costs, including costs of pumps and of labor, must be estimated carefully before decision is made as to a nursery site.

A loam or sandy loam soil is the most satisfactory. Unless the land is very low and flat it is preferable that the loam be underlain by some slightly less permeable soil, since this decreases both moisture loss in dry weather and leaching of plant nutrients throughout the year. The surface soil should preferably be not less than 12 or

14 inches deep, so that plowing and, especially, any leveling that may be done will not expose the heavier subsoil.

Fairly sandy soils frequently meet all forest-nursery requirements if they are underlain by less pervious soils. The cost of enriching such soils with various fertilizers is offset by greater ease of working, and most species of pine develop better root systems in light than in heavy soils. Every effort should be made to avoid stiff soils, and to choose soil that will neither wash badly in rainy weather nor puddle during rain and cake and crack thereafter.

Southern pines thrive on slightly to moderately acid soils (pH 6.5 to 4.5).

The small number of species ordinarily grown in a southern pine nursery, and the lack of need of transplanting, make it unnecessary that the nursery contain a variety of soils. In fact, the more uniform the soil the better, as soil uniformity simplifies nursery practice and results in greater uniformity of product.

It is important that drainage be at least moderately good. "Crawfish land"[7] is undesirable, and a nursery should never be established on land at all likely to be flooded by stream overflow or by backwater.

A relatively level site is preferable. On slopes exceeding 3 percent most of the soil types adapted to the production of southern pine planting stock wash too easily to be desirable.

North and east exposures are preferable to west and, especially, to south exposures, because they have less tendency to dry out seriously and also because they involve less heat injury.

Planting stock of southern pines can be grown with fairly regular success by a competent nurseryman even on an adverse site, if the water supply is adequate. Stock of the best grade, however, can be produced only on soil naturally fertile or easy to fertilize, well drained, of good moisture-holding capacity, and easy to cultivate; and the better the site the more cheaply a given quality of stock can be produced.

Among several otherwise equally desirable nursery sites, choice should rest on the one where there seems to be least danger of infection with disease, infestation by insect pests, or attack by injurious animals or birds. In particular, a nursery in which longleaf pine is to be grown should be placed as far as possible from young stands of longleaf pine seriously infected with brown-spot needle blight. It is undesirable that a nursery be located near pecan groves or stands of other hardwood species the leaves of which furnish food for adult May beetles, since larvae of this insect are a nursery pest. Grasslands in particular are apt to harbor large grub populations.

It is well that the location of a nursery allow plenty of room for expansion.

LAY-OUT

The area desirable for a nursery varies not only with the quantity of stock to be produced but also with the species of the stock, the method of sowing to be used, optimum stand density as determined

[7] This term is applied to soil so poorly drained that it remains moist enough to furnish a home for semiterrestrial crawfish (*Cambarus* spp.). Such soil is difficult to work and unfavorable to the growth of pines, and the crawfish destroy much nursery stock by covering it with mounds of mud thrown out of the mouths of their burrows.

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by character of soil, and the schedule of soil-improvement crops found necessary to keep the nursery soil in good condition. Drill sowing calls for somewhat more space than broadcast sowing. The lowest desirable density is usually about 20 seedlings per square foot, and the highest not more than 60. (Desirable densities for individual species are discussed on p. 46.) Table 12 shows the approximate areas, in square feet and in numbers of 4- by 50-foot beds, required to produce 100,000 seedlings at each of several densities.

TABLE 12.—*Net and gross areas and numbers of beds required to produce 100,000 seedlings at different densities when drill sown or broadcast sown*

Drill sown				Broadcast sown			
Seedling density (number)	Beds	Net bed area	Gross bed and path area	Seedling density (number)	Beds	Net bed area	Gross bed and path area
Per running foot:	*Number*	*Sq. ft.*	*Sq. ft.*	Per square foot:	*Number*	*Sq. ft.*	*Sq. ft.*
10	25.0	5,000	7,500	20	25.0	5,000	7,500
12	20.8	4,170	6,250	25	20.0	4,000	6,000
15	16.7	3,330	5,000	30	16.7	3,330	5,000
18	13.9	2,780	4,170	40	12.5	2,500	3,750
				50	10.0	2,000	3,000
				60	8.4	1,670	2,500
				75	6.7	1,330	2,000

[1] Beds are 50 feet long and 4 feet wide; paths 2 feet wide. Drills 6 inches apart.

Hand weeding is difficult in beds more than 4 feet wide and practically impossible in beds more than 5 feet wide. The standard width in the southern pine region is 4 feet. Beds may be of any desired length, but usually are much longer than the 12 feet common for many years in other regions. Beds 25 feet long are sometimes used if frames or covers of any sort are required, but still greater length is usually preferable because it reduces charges for both labor and materials. One State nursery uses beds 500 feet long. A bed 50 feet long and 4 feet wide is a convenient areal unit on which to base estimates as to quantities of seed or fertilizer to be used or of stock to be grown and shipped.

In a nursery having an overhead sprinkling system, it is preferable that the length of the beds parallel the sprinkler lines. This permits grouping beds in blocks according to the sprinklers by which they are watered. All the beds of a block supplied by a given line can be made up and sown at one time and be wet without wasting water or disturbing unsown beds. If arrangement with regard to sprinkling lines does not conflict, it is best to run the beds up and down the slope in nurseries that are nearly level or are poorly drained, and across the slope where slope is steeper, to retard run-off and reduce soil wash.

The size and arrangement of paths and roads depend so largely on conditions and management details of the individual nursery that no general rule can be laid down. Paths 2 feet wide, besides being more comfortable for workmen than narrower paths, allow room for wheelbarrows. Narrower paths are preferable where limitation of space makes it necessary to devote more than two-thirds of the nursery area to the beds themselves, or where the water supply is so

limited that it is particularly desirable to avoid wasting water on paths.

Nurseries less than an acre in area seldom need interior roads. The larger the nursery, the greater the need of permanent roads. Nursery roads should always be so laid out that passing and turning will require minimum space and time.

Tanks, pumps, and main pipe lines, for greatest efficiency, must usually be located at the upper side of the nursery. The location of the main feed line must be selected very carefully if water is to be supplied by gravity or applied to the beds by irrigation. A little sketching and measuring on a map of the nursery before the watering system is installed may result in substantial saving through more efficient arrangement of pipe lines.

It is always wise to construct a good fence around the nursery, to protect it from livestock or vandals. The fence should have two gates, so that trucks can pass through the nursery without turning. The gates should be well enough designed and constructed to stay closed when shut, to swing open at a touch, and not to swing back against an entering car or truck.

The nurseryman's living quarters should be at the nursery or close enough to enable him to watch developments daily throughout the year.

PREPARATION

Nurseries are plowed and harrowed according to the agricultural practice suited to the locality, except that the soil is not thrown up into rows or hills as it would be for cotton or certain other crops. Plowing should be deep enough to provide good growing conditions for roots to a depth of 8 inches, but not deep enough to expose any subsoil unfavorable to the seedlings.

The choice of harrow depends not only on the character of the soil but also on the character of the weeds most likely to cause trouble in the nursery. The presence of coco grass (*Cyperus rotundus* L.) makes it undesirable to use harrows other than the disk harrow, because they spread its bulbs. If coco grass is absent, certain forms of toothed harrows can sometimes be used to work roots of Bermuda grass (*Capriola dactylon* (L.) Kuntze) to the surface. A device known as a whirling harrow has been used very effectively for this purpose.

Seed beds should be laid out accurately as to size and perfectly as to alinement, unless some peculiarity of the nursery soil makes it necessary to fit the system of beds very closely to the contours of the land. A slipshod lay-out spoils the nursery's appearance and has an unwholesome effect on the attitude of nursery foremen and crews, making for slackness and carelessness in all operations.

Methods in common use for laying out beds vary all the way from regular engineering use of transit and steel tape to various simple applications of measuring stick and cord. One nurseryman working with small but experienced crews lines out his larger blocks of beds, his roads, and other main features with a steel tape, stretches cord along the boundaries of the blocks, and marks these boundaries by rolling a wheelbarrow wheel over the freshly prepared earth. Next, with the help of one man, he stretches cord across the block at

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alternate intervals of 4 and 2 feet and again uses the wheelbarrow wheel to mark out beds and paths. He then plows along the marks with a light turning plow and sets his bed curbs in the shallow furrows, checking the distance from curb to curb with a 2- or 4-foot stick.

On level land, particularly if the nature of the soil prevents good drainage, the beds must be built up above the level of the paths. If the soil washes seriously, curbs are necessary to keep the beds in shape. These are made of low-grade lumber, usually 1 by 4's or 1 by 6's, nailed to pegs or stakes. To leave such curbs around the beds throughout the growing season is a mistake, except on soils that wash very badly; ordinarily they should be removed in June or July, as soon as the seedlings are large enough to protect the soil. The latter practice, making use of available labor at a slack season, adds a year or two to the life of the curbs by getting them out of contact with the ground, and saves time during lifting, when time is particularly precious. The curbs must of course be stacked properly after removal, or removal from contact with the soil will fail to save them from rotting.

In nurseries where soil washing is not severe, particularly where the beds need not be built up very high, the wooden curb has given way to the unsowed shoulder, that is, a strip at the edge of the path built up to the level of the bed. Such a shoulder is usually 6 inches wide; on soils only slightly subject to washing, it need not be more than 3 inches wide. During the spring and early summer months the shoulder is worked down into the path by washing and trampling, so that by the time the seedlings are large enough to protect the soil it has been eliminated. The use of the shoulder saves not only the cost of curbs but also a considerable labor cost.

On poorly drained soil, or in localities having heavy rainfall, the surfaces of beds should be rounded slightly to keep water from standing on them after rain. On very light sandy soils where a water-retentive subsoil is very far down or is altogether lacking, or in the localities of scanty rainfall near the western edge of the southern pine region, beds should be practically level, for maximum utilization of available moisture.

Southern pine seed germinates less quickly and readily than agricultural seed, and the seedlings themselves are slower to develop and more subject to injury than the young plants of most agricultural crops sown direct in the field. The seed bed must therefore be finished more carefully, and the soil pulverized more finely, than is necessary with many agricultural crops. Hand spading, or a thorough working of the soil with potato hooks, is not uncommon practice in the finishing of seed beds, even after careful plowing and harrowing. Raking is universally practiced, and skillful rakers are a great asset to a nursery crew. In some nurseries, the beds are given a final smoothing and rounding or leveling with a hand drag which leaves the surface finely pulverized.

Soils differ remarkably in their requirements as to final treatment before sowing. In some nurseries, it is a regular practice to make up the beds several weeks in advance of sowing so that the soil will settle to its final position under the impact of late winter or early spring rains. Raking to a depth of 1 or 2 inches then

puts the surface of the bed into best condition for sowing. In other nurseries, even a single soaking rain after the beds are made up necessitates respading the beds before sowing them, and any settling must therefore be done by means of rollers. On a few soils, even rolling before sowing is injurious and when raking is completed the beds must not be left unsown overnight because of the risk of damage by rain.

FERTILIZING AND OTHER SOIL AMENDMENTS

In southern forest-tree nurseries, largely because most of them have been laid out on fairly good soil and have not been in existence long, the use of either soil crops or fertilizer on a commercial scale has barely begun, and practically no systematic experiments with nursery fertilizers have been undertaken.

The object of fertilizing forest-tree nursery soils is to obtain larger seedlings in less time and at a lower final cost.

Southern nursery soils are typically somewhat acid. They are likely to be deficient or almost totally lacking in organic matter; and such a lack not only limits a soil's fertility and water-holding capacity but also makes its physical condition less favorable to proper development of seedling roots. Some soils are too heavy and stiff, others too light and hence sterile and dry, according to origin and topographic situation.

The fertilizers usually applied to pine seed beds are nitrogen, phosphorus, and potassium in the form of compounds that are immediately available to the plants as nutrients or that break down more or less rapidly, under the influence of weathering, into available nutrients. These elements can be added as concentrated commercial fertilizers, either nonorganic (such as sodium nitrate) or organic (such as tankage or bone meal). Nitrogen can be added in the form of barnyard manure or hen manure. Most fertilizers are added to the soil and worked into it at the time when the beds are prepared. The chief exceptions are sodium nitrate and ammonium sulphate, which are applied at intervals during the growing season, usually in solution, when it appears that the seedlings are not increasing normally in size. Nitrogenous matter, and much other organic matter tending to improve the physical character of the soil, can be added by growing various leguminous soil crops and plowing them under. Cowpeas and soybeans are among the soil crops most generally satisfactory in the southern pine region. *Crotalaria spectabilis* appears to be almost equally valuable. Nitrates tend to make soil alkaline; where species to be grown are susceptible to damping-off, ammonium sulphate is preferable unless the soil is strongly acid.

Very heavy applications of almost any fertilizer may cause injury or high mortality among young southern pine seedlings, particularly of the smaller-seeded species. It is possible that organic matter decreases germination; and it has been suggested (*22*) that abundant organic matter in the soil, by increasing damping-off, inhibits the early development of longleaf-pine seedlings to the point of determining the range of this species. A disproportionately high quantity of nitrogen is likely to cause vigorous top growth without corresponding root development, and may lead to heavy mortality of seed-

lings planted on a dry site or subjected to drought during their first season in the field. Better root development may be brought about by increasing the quantity of available phosphorus. Application of any highly soluble fertilizer late in the growing season may prevent proper hardening of the stock at the approach of cold weather; but a light application even as late as September sometimes enables poorly developed stock to make a final spurt of growth and thus reach a size suitable for planting. Fresh stable manure sometimes has an unfavorable effect on seedlings, particularly if it is not well broken up and worked into the soil, but well-rotted manure in quantities up to 1 ton per acre is usually an excellent addition to any soil.

Sand, charcoal, rotted hardwood sawdust, and commercial or florists' peat sometimes make valuable additions to heavy or poorly drained soil, though charcoal may possibly increase liability to heat injury. Rotted sawdust and commercial peat may improve the quality of very light sandy soil also. These two materials combine well with fresh manure or fresh weeds to form a compost that, after a year or two in the heap, adds to the soil readily available nitrogen and desirable organic matter. It is not good practice to compost weeds unless they are pulled before coming into bloom, or unless they are free from long-lived roots or bulbs.

SOWING

What season is best for sowing depends on what species of pine is to be grown; on the latitude, elevation, and local situation of the nursery; on soil conditions and the prevalence of various insect and fungous pests; and on the kind and abundance of weeds.

Loblolly and shortleaf pine seed should in general be sown early, in the Gulf States perhaps by March 1 at the latest. In the Forest Service nursery at Russellville, in north-central Arkansas, January seems to be the best time to sow shortleaf pine. In the northeastern part of the region, where freezing weather ordinarily makes nursery work impossible for a certain period each winter, it may prove desirable to sow seed of loblolly and shortleaf pine in November, practically as soon as it has been extracted. Seedlings of loblolly and particularly of shortleaf pine grow less rapidly than seedlings of longleaf and slash pine, and must have the longest possible growing season if they are to become large enough to plant in the winter following sowing. Moreover, loblolly pine seed, and sometimes shortleaf pine seed as well, germinates more promptly and completely if sown as soon as outdoor temperatures become high enough to permit prompt germination than if stored at room temperature until late in the spring. Seed of these species may germinate still better if it lies in contact with moist soil during a period of cold weather before being subjected to temperatures favorable to germination. Promptness in germination is desirable both because it simplifies the treatment of seed beds, especially watering and the removal of mulch, and because it results in greater uniformity of stock at the end of the season.

Slash pine seed is adapted to fairly late sowing. The seed ordinarily germinates promptly and completely, and the seedlings de-

velop so rapidly under favorable conditions of soil and climate that if started early they may be too large for planting by the end of their first growing season. Slash pine can ordinarily be sown to best advantage in early or middle March.

Longleaf pine seed should be sown earlier than slash pine seed, because the seedlings grow somewhat less rapidly and need a longer season to develop into grade 1 stock.

The higher and more northerly the location of the nursery, the earlier should the seed be sown. The farther south and the nearer sea level the nursery lies the better is the growth rate adapted to late sowing, but, on the other hand, the more likely is late sowing to result in poor germination and to subject the seedlings while they are still in the cotyledon stage to heat and drought severe enough to prevent their best development. Data from several nurseries in the southern part of the region indicate that sowing should not be postponed beyond April 1. Detailed data from experimental sowing in two such nurseries at intervals throughout the winter and spring are given in table 13.

TABLE 13.—*Germination percentages, and size of 1–0 stock, in 2 nurseries at Bogalusa, La., by season of sowing*[1]

Nursery and date of sowing	Longleaf pine				Slash pine			
	Total germination	Final tree production	Average length		Total germination	Final tree production	Average length	
			Needles	Roots			Tops	Roots
Nursery A:	*Percent*	*Percent*	*Inches*	*Inches*	*Percent*	*Percent*	*Inches*	*Inches*
Nov. 13, 1924	86.4	61.8	16.2	23.3	33.1	18.9	11.2	18.3
Dec. 15, 1924	84.2	70.2	15.2	20.6	30.3	20.1	8.6	12.8
Jan. 17, 1925	78.4	64.6	15.2	20.0	25.1	20.1	7.4	13.5
Feb. 13, 1925	76.2	69.8	11.5	19.2	15.2	14.5	7.3	17.6
Mar. 12, 1925	72.4	56.6	7.8	16.8	13.9	8.0	5.6	11.6
Apr. 18, 1925	10.4	2.8	7.2	17.2	1.7	0.0	----------	----------
Nursery B:								
Dec. 4, 1925	85.6	66.4	14.0	21.9	39.2	32.3	7.7	16.5
Mar. 11, 1926	80.4	72.2	----------	----------	49.5	41.1	----------	----------

Nursery and date of sowing	Loblolly pine				Shortleaf pine			
	Total germination	Final tree production	Average length		Total germination	Final tree production	Average length	
			Tops	Roots			Tops	Roots
Nursery A:	*Percent*	*Percent*	*Inches*	*Inches*	*Percent*	*Percent*	*Inches*	*Inches*
Nov. 13, 1924	57.5	53.3	7.7	11.6	23.5	22.0	6.1	14.3
Dec. 15, 1924	57.9	53.9	8.8	12.2	23.9	22.5	5.4	13.6
Jan. 17, 1925	49.1	47.5	5.0	14.0	20.6	18.8	4.5	10.5
Feb. 13, 1925	33.2	30.4	5.1	15.6	19.0	17.4	4.6	12.4
Mar. 12, 1925	17.1	16.8	4.2	14.3	13.0	11.5	3.4	13.3
Apr. 18, 1925	2.0	0.5	6.8	14.3	8.8	6.5	4.1	12.2
Nursery B:								
Dec. 4, 1925	63.7	59.9	----------	----------	48.3	44.8	----------	----------
Mar. 11, 1926	46.8	42.9	----------	----------	38.4	34.9	----------	----------

[1] Seed was covered with sand to a depth of from ⅛ to ¼ inch. Shade removed June 20, 1925, in nursery A, and June 24, 1926, in nursery B. Basis of table: Germination percentages, 5 drills each 4 feet long; lengths, 50 or more seedlings in each instance except for the Apr. 18 sowing in nursery A, from which the longleaf average represents 13 seedlings and the loblolly average represents 3 seedlings. "Final tree production" is the percentage of seeds sown. "Average length" is at end of growing season.

Other things being equal, seed should be sown earlier on poor soil than on rich soil, so that lower fertility will be offset by a longer growing season. This is particularly true of longleaf and shortleaf pines. Since slash pine seedlings on fertile soil tend to grow in one season beyond the size suitable for planting, in especially fertile nurseries it is sometimes necessary to postpone sowing of slash pine seed to the latest date consistent with safety from drought and heat.

Control of practically all pests and weeds is favored by late sowing rather than very early sowing. The briefer the period during which the stock is in the seed beds the less opportunity pests have to injure it. In particular, moderately late sowing shortens the period during which the seedlings remain in the cotyledon stage, in which they are especially subject to insect attack and damping-off. If sowing is postponed until fairly late the first crop of weeds starts before the pine seed is sown, and can be gotten rid of by harrowing or hoeing instead of by the more expensive hand pulling.

Moderately late sowing simplifies nursery administration because it allows time for making up, settling, and resowing the beds in the same season in which one crop of seedlings has been lifted from them for planting, and because it spreads nursery work over a long period instead of making the work of sowing coincide with that of lifting.

In starting a new nursery, it is a good plan to lay out a series of small experimental beds and sow 1 or 2 each month from January to April, inclusive, in order to determine what month is preferable for sowing the main crop.

Theoretically, broadcast sowing results in greater uniformity of stock and in better use of all available plant nutrients, soil moisture, growing space, and light, than drill sowing. Certainly some of the finest nursery stock so far produced in the South has been grown from seed sown broadcast. In general, however, in the southern pine region the rapid growth and early removal of the seedlings, the class of labor frequently employed for nursery work, and the luxuriant growth of weeds give drill sowing a slight advantage in economy of operation and quality of stock. In particular, drill-sown seedlings are much easier to thin than broadcast seedlings. Drill-sown stock requires ordinarily about 20 percent more seed-bed area, and in extreme cases as much as 50 or 60 percent more. Ordinarily, however, the cost of clearing, fencing, and preparing extra land, and the taxes on extra land, appear to be more than compensated for by the difference in cost of weeding, particularly if the drills are far enough apart to permit hoeing out most of the weeds.

In the South broadcasting is usually done by hand. In preparation for broadcasting by hand it is best to weigh out the quantity of seed needed for each bed and divide it in halves or quarters, so that each half or quarter of the bed can be sown separately. It is well to divide the seed set aside for a given portion of a bed into two lots of unequal size, and after sowing the larger lot as evenly as possible to fill in with the remaining lot all spots missed the first time. These practices not only result in a more uniform distribution of seed, but enable the sower to work more rapidly.

In drill sowing, the first step is to determine carefully the number of seeds to be sown in each drill, and their volume. It is then

possible to make a measuring cup that will hold almost exactly that quantity of seed. An aluminum gelatine mold cut down with tin snips is good for measuring longleaf pine seed, and a 10-gage or 12-gage shotgun shell cut down with a knife is good for measuring seed of the other species.

In small operations, particularly if skilled labor is available and there is no great need of haste, sowing in drills may be done by hand, either with the fingers or directly from the measuring cup. In a nursery with a capacity of more than 100,000 seedlings, it is commonly much more desirable to use a seeding trough.

Many devices have been designed for sowing seed, some of which permit sowing several drills at a time. In regard to the design of such devices, one important point is the extreme fatigue involved in squatting down to manipulate a low trough that must be opened

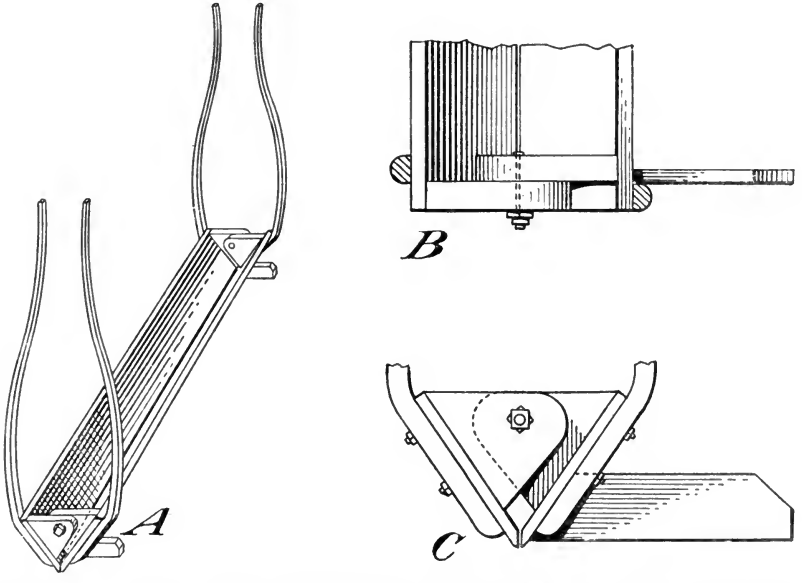

FIGURE 8.—*A*, Trough used for sowing seed in drills in the nursery, showing also top view (*B*), and side view of end (*C*).

and shut 100 or more times in the process of sowing a 50-foot bed. Another is the fact that seeds are very likely to get between any sliding parts, such as the layers of the triple-bottomed Michigan drill seeder, and jam them.

A difficulty in using any of the more common seeding machines with longleaf pine seed arises from the fact that the wings of seeds of this species make them very bulky and prevent them from sliding through easily.

A seeder that is perhaps more effective than any other developed in the South is shown in figure 8. It consists of a trough constructed to open at the bottom. Two 6-inch boards 4 or 5 feet long, according to the width of the beds on which the seeder is to be used, are joined at the ends by triangular wooden blocks screwed to them and bolted to each other, which rotate when the upper edges of the

boards are pushed toward each other. The trough is equipped with two pairs of curving handles about 3 feet tall. At its ends are horizontal markers of such length that when their ends are set in the first drill the trough is in correct position to sow the second drill.

The two men operating the trough are each equipped with a bucket of seed and a measuring cup that holds enough seed for half a drill. They set the closed trough down on the freshly prepared bed, on the surface of which the trough, by its own weight, makes a shallow drill. Each man fills his measuring cup with seed and distributes it along the trough from his end to the middle, then each grasps the handles at his end of the trough and pushes them together, opening the trough at the bottom and depositing the seed in the drill. With this device 2 men can easily sow 200 drills 6 inches apart, or 100 linear feet of bed, in an hour. Sowing at this rate, if it results in production of 15 seedlings per foot of drill, requires only 0.167 man-hour per 1,000 seedlings in beds 4 feet wide and only 0.133 man-hour per 1,000 seedlings in beds 5 feet wide.

How many seeds should be sown per unit area of broadcast bed or per running foot of drill depends first of all on the seed-bed density most desirable for the species concerned, which in turn depends in part on the productivity of the soil.

Table 14 gives densities desirable during the latter part of the growing season for seedlings growing in nursery soil of average quality in broadcast and drill-sown beds, respectively. On especially fertile sites seedlings can be grown satisfactorily a trifle closer than indicated in the table; one nurseryman in South Carolina produces unusually good longleaf pine seedlings at a density of approximately 40 per square foot. On soils less productive than the average—particularly on dry sites or in localities of high temperature and low rainfall—or in nurseries lacking a liberal supply of water, it is frequently necessary that the densities be one-third or even one-half less than those shown in the table. In a comprehensive series of tests at the University of Georgia in which seedlings were grown from broadcast sowing at densities varying from 10 to 80 per square foot, the largest and best longleaf pine seedlings obtained were those grown at a density of 10 per square foot, and the largest and best slash and loblolly seedlings were those grown at a density of 30 per square foot.[8]

TABLE 14.—*Desirable final densities for seedlings grown in nursery soil of average quality*

Species	In broadcast-sown beds	In drills 6 inches apart
	Number per square foot	*Number per foot*
Longleaf	25–35	10–12
Slash	35–45	12–15
Loblolly	40–50	12–15
Shortleaf	55–70	15–18

[8] MAY, J. T. EFFECT OF DENSITY OF STOCKING ON THE GROWTH AND DEVELOPMENT OF LONGLEAF, LOBLOLLY, AND SLASH PINE SEEDLINGS. 55 pp. 1933. (Unpublished thesis, Univ. of Georgia.)

Since rent and charges for water and weeding are the same no matter how many trees are grown per unit of seed-bed area, the cost per 1,000 trees is unnecessarily high if fewer good trees are grown than the soil is capable of producing. In addition, isolated seedlings fail to shade the ground so effectively as those grown at optimum density, and this deficiency of shade or some factor associated with it results in poorer quality of stock. It is better to sow too much seed and obtain too dense a stand than to sow too little, because thinning is easy and inexpensive but to bring an understocked seedling stand up to normal is impossible. Seed-bed thinning should be done late in May or in June, after the period of heavy juvenile mortality but before the seedlings are large enough to crowd each other seriously. Snipping off the excess seedlings with small scissors is quicker than pulling them, and much less likely to injure the seedlings that remain.

The computations necessary to determine nursery requirements on the basis of the results of seed tests have been described in the section on seed testing (p. 31.) As a general rule when fresh seed of high quality, that is, seed with a germination percentage of 90 or more, is sown under conditions conducive to abundant and vigorous germination 40 to 50 trees are produced for every 100 seeds sown. Seed with a germination percentage much lower than 90, or seed sown during adverse seasons or under unfavorable nursery conditions, cannot be expected to produce more than 20 to 40 trees per 100 seeds sown.

COVERING, ROLLING, AND MULCHING

Seed requires a covering to keep it moist from the time it is sown until it germinates, to assist it in taking root, and to protect it from birds. The southern pines as a group react unfavorably to a soil cover of any considerable depth during germination, as has been noted in connection with germination tests. Experiments and experience in southern pine nurseries have demonstrated conclusively that the most favorable depth of soil or sand cover is approximately one-eighth inch, and that any covering deeper than one-quarter inch decreases germination seriously or prevents it altogether.

In many nurseries, rolling the seed beds makes easier the application of the covering, in addition to settling the beds; in few nurseries is the soil of such peculiar composition that rolling does more harm than good. Some nurserymen prefer to roll the beds before they sow the seed, especially if the seed is to be sown broadcast and covered with soil or sand; others prefer to sow broadcast on a freshly raked bed or in shallow drills and roll after sowing, thus covering at least part of the seed. Some who make use of a cover other than soil prefer to roll after sowing but before applying the cover, others prefer to roll after the cover has been put on. The most effective practice must be worked out for each nursery in accordance with its needs.

The roller should always extend the full width of the bed, and should be heavy enough to pack the soil uniformly and firmly. Weights of 300 or 400 pounds have been found suitable. A hollow roller the weight of which can be adjusted by pouring in water, to

suit different soils and different conditions of soil moisture, is particularly useful. The larger the diameter of the roller, the less rolling disturbs the seed by pushing up the soil. The Forest Service has obtained very satisfactory results with hollow wooden rollers 4 or 5 feet in diameter.

Burlap, preferably of the 10- or 12-ounce grade, is widely used for seed-bed covers, since it is easy to apply and is an effective protection against birds. It may be tacked to the bed curbs or pinned down to the ground with U-shaped wires. Care must be used in laying it, to avoid disturbing the distribution of seed; and in removing it, to avoid destroying seedlings.

Burlap cover usually should remain on the beds for 3 or 4 weeks after sowing. Earlier removal may leave a large portion of the seed unprotected. If it is left too long, many seedlings may be crushed or smothered, or become subject to damping-off, while others may work through the cloth and so be destroyed. If germination is prompt and vigorous, the burlap usually may be removed when counts on small areas chosen at random show that about two-thirds of the expected germination has taken place. If germination is slow and irregular, and sometimes even if it is fairly prompt, the burlap should be left on until seedlings begin to smother beneath the cloth or to push up through it. Longleaf pine seedlings seldom push their way through burlap, because their stems are too short and their cotyledons too thick. If other seedlings push through, some of them may be saved if the burlap is removed in the afternoon, when the seedlings have wilted a trifle and are pliable.

The use of burlap is not entirely satisfactory, because some soils pack badly under it during heavy rains; also it tends to rot in storage during the summer unless it is dried with great care after being removed from the beds.

A thin layer of pine needles (locally called pine straw) is coming into general favor as a combined cover and mulch. Usually, it costs less than burlap. Seed-bed soil is less subject to packing by rain under the straw covering than under burlap, and germinating seedlings suffer less from crushing or smothering under straw.

Pine straw for use as cover and mulch is raked from the ground under young stands. An effort is made to keep it relatively free from twigs, bark, and cones. It is scattered over the freshly sown bed in a layer one-half to 1 inch thick. This layer settles rapidly, or may be rolled flat in the process of firming the surface of the seed bed. In its final form, it should just hide the seed from view. To prevent injury to the seedlings, it must be removed from longleaf pine seed beds when germination is not quite complete; on seed beds of the other species, it may be removed at that stage or one-half to two-thirds of it may be removed then and the rest left in place for weeks or months, according to the kind and abundance of weeds in the bed.

In the Forest Service nursery at Russellville, Ark., where shortleaf pine seed is sown in January, a mulch of clean wheat straw is used on top of a light covering of sand to prevent frost heaving. Need of such mulching is not usual in southern pine nurseries.

Several trials of paper mulches have been made in southern-pine nurseries, but with unsatisfactory results. Such mulches are not well

adapted to small plants grown in great numbers and in even, close distribution. It is difficult to sow seed between strips of paper mulch, and if the seed is sown first it is likely to be covered. The mulch is hard to anchor. Because of the nature of the crop, as much as 20 or 30 percent of the soil must be exposed; and this gives the weeds plenty of chance to come up among the crop plants. In the few instances in which a paper mulch has been put in position and kept there, no appreciable improvement in the quality of the pine seedlings could be observed.

EARLY PROTECTION

Agencies that may injure southern pines between the time of sowing and the time when the seedlings are well out of the cotyledon stage and have put on considerable juvenile (single needle) foliage, that is, from February or March until May or June, include frost, birds, rodents, moles, cutworms, and damping-off. Frost does little or no harm in most southern nurseries, but occasionally causes some damage in winter-sown beds, especially in the northern part of the region. In localities where frequent freezing and thawing of the ground is known to occur, sowing should be postponed until the danger of frost has passed in the spring or, if winter sowing is necessary, the beds should be mulched with needles or grain straw or the seed should be covered with one-eighth to one-fourth inch of pure sand.

Birds are among the greatest destructive agencies, particularly to longleaf pine and on areas near gathering points of migrating flocks. A large flock of birds can practically ruin a small nursery in the early morning hours of a single day. According to reports from a dozen nurseries the most injurious species are, in order, doves, meadow larks, bobolinks (reedbirds), domestic pigeons, and cardinals. Other species may exceed these in destructiveness in some places. Bird screens made of fine chicken wire on light wooden frames are effective, but are expensive to build and handle and do not last many seasons. The use of screens is not generally recommended. If bird damage is known to be only moderate in quantity, the seedbed cover used during germination can frequently be depended on for protection. Burlap cover is better than pine straw in this respect. If birds are very numerous, the most satisfactory protective measure is to employ reliable laborers to patrol the beds with sling shots, air rifles, or shotguns, from just before dawn until after dusk. Damage by birds ceases once the cotyledons are free from the seed coats; therefore 2 months is the longest period during which a patrol is likely to be needed. Care must be taken to avoid coming into conflict with the Federal Migratory Bird Treaty Act and with State laws, which protect many of the bird species that commonly injure seedlings. In a few instances it has proved effective to feed the birds oats or cracked grain at one side of the nursery. Coating pine seed with red lead or other repellents seems to have no effect in the South, and scarecrows and similar devices have proved useless.

A sharp lookout should be kept for signs of injury by rodents. An effective mode of control is to scatter poisoned bait on the nursery

and adjacent areas before seeding. A formula for a bait for field mice is given in the appendix (p. 111).

Moles, tunneling in the nursery, sometimes cut up the soil so seriously as to destroy considerable quantities of seedlings. Their food, however, consists entirely of animal matter, including white grubs and many other insects. It may be, therefore, that their presence on areas near the nursery, and in portions of the nursery temporarily in soiling crops, is definitely beneficial. If their tunneling damages the seed beds excessively, systematic use of any of the standard mole traps is a satisfactory method of control in commercial nurseries. Detailed instructions for controlling moles are given in Farmers' Bulletin 1716 (*27a*).

Cutworms, the caterpillars of several very common species of moths, sometimes attack seedlings in the cotyledon stage. Cutworm injury first becomes noticeable as a sudden thinning of the very young seedling stand, and is likely to be confused with the effects of damping-off. Close examination shows that the stems of the seedlings have been bitten completely or part way through. Cutworms are ordinarily easy to control by using a poisoned bait described in the appendix (p. 112). As the worms feed principally at night, the bait should be scattered through the nursery just about sundown, so that it will have no time to dry out before the worms begins to feed.

Seedling diseases of the group known as "damping-off", caused by fungi of various species, are neither so general in occurrence nor so severe and persistent in the South as in the North and West. This may result partly from the greater acidity of southern nursery soils, as most of the fungi causing the diseases prefer nearly neutral or even slightly alkaline soils, or it may result from the greater resistance and more rapid initial growth of southern pine seedlings.

In its most typical form damping-off occurs in seedlings in the cotyledon stage and causes the roots to die and turn watery brown and the stems to topple over and become so limp that they drop into any depressions in the soil surface. Freshly germinated longleaf pine seedlings, having stems too short to topple over easily, when attacked by damping-off fungi often flatten out on the ground like little rimless wheels. In its more obscure form, damping-off occurs in germinating seed before the seedlings appear above the surface of the ground and often remains a good deal of a mystery to the nurseryman. This phase of the disease may account for the lack of success in beds and germination tests in which the seeds are covered with soil more than one-fourth inch deep. An infrequent form called "top damping-off" occurs in the tops of the seedlings as late as May or June.

Factors contributing to damping-off are overcrowding, poor drainage, too much rainfall or artificial watering, the addition of too much organic matter or of lime or wood ashes to the soil, and too much shade. The infrequent top damping-off can be controlled by providing ventilation; thinning may be needed in extremely dense stands. The so-called "late damping-off", really a root rot caused by the damping-off fungi after the stems are too stiff to fall over, has not been observed in the South. To protect sprouting seed and very young seedlings from the usual type of damping-off, acid

treatment, either with sulphuric acid or with the more convenient aluminum sulphate (*17*), is the most generally successful. At nurseries where damping-off is feared and where the soil acidity is materially less than that represented by pH5, such treatment should be tested on a small scale. Either material may be applied to the beds just after they are sown and covered; the amount to use per square foot varies from one-eighth to three-eighths fluid ounce for sulphuric acid, and one-fourth to 1 ounce for aluminum sulphate, the largest amounts being needed or tolerated only on heavy or alkaline soils. For such surface treatment, the materials should be dissolved in water at the rate of 1 to 2 pints per square foot (the smaller amount only if the soil is already moist), and the beds should be promptly sprinkled. Modifications of the acid type of treatment are now being made, and the most recent information can be secured by application to the Division of Forest Pathology, Bureau of Plant Industry, at Washington. Because different soils differ in their requirements and tolerance for acid treatments, they should not be used on a large scale until after small-scale local tests.

Where it is very essential to insure against failure of first-year seedling production on an untried nursery area, the formaldehyde treatment may be used without previous trial. The treatment is applied at the rate of two-thirds fluid ounce of the strongest (37-percent) liquid formaldehyde per square foot of bed, dissolved in approximately 2 pints of water per square foot. The beds must be exposed to evaporation for a week, or, if the weather is cold, for 2 weeks, before the seed is sown. The soil should not be turned over deeply after treatment; no soil cover other than treated soil, or clean river or subsoil sand, should be used on the treated beds. The treatment is more expensive, and usually less effective against either disease or weeds, than a proper strength acid treatment, but can be counted on to be of some value on almost any soil type.

Another still more expensive but usually safe method is that of steaming. The Maryland State Department of Forestry has successfully controlled damping-off fungi and greatly reduced weeds in beds of loblolly pine and other species by a modification of this method in which a 4- by 12-foot inverted pan supplied from a small portable steam boiler is left in place 30 minutes, with steam at 40 to 60 pounds per square inch, heating the soil at a depth of 4 inches to a temperature of from 160° to 180° F. Loblolly pine has grown better in beds steamed by this method than in adjacent unsteamed beds. Scheffer (*24*) has found it effective to use very low pressure steam for the same purpose, and describes the procedure in some detail.

SHADING

Shades over seed beds are seldom necessary in southern pine nurseries, because of the exceptional resistance of southern pine nursery stock to high surface-soil temperatures.[9] Need of shades is least for seedlings growing at correct densities and for seedlings large enough to shade the ground around their root collars.

[9] Studies in California, the Northeast, and other forest regions of the United States have shown that surface soil temperatures higher than 120° F. are generally dangerous to small coniferous seedlings in those regions.

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In a nursery at Bogalusa, La., the maximum surface soil temperature of 1928 in an unshaded bed was 132° F., recorded on July 9. The corresponding surface-soil temperature in an adjacent bed under a lath "half shade" was 114°. In this and in two other nurseries at Bogalusa in which shading experiments were made, the results were distinctly better in the unshaded beds except that the smaller seeded pine species (loblolly and particularly shortleaf) tended to germinate and occasionally to survive better under shade. Longleaf and slash pine in unshaded beds germinated and survived as well as they did in shaded beds, and in several instances much better. All four species developed markedly stouter, heavier seedlings in the absence of shade.

On the Ozark National Forest, Ark., unshaded shortleaf pine 1-0 stock planted in the spring of 1932 survived far better than corresponding shaded stock.

Use of shade sometimes causes considerable injury. It apparently increases very greatly the loss from damping-off. It also causes rapid elongation of the stems of the surviving seedlings and makes the plants tall and spindling. Shaded seedlings continue to develop juvenile foliage long after similar plants grown in unshaded beds have put out abundant fascicled needles. Not only are they undesirable in form but they lack hardiness, because of delay in developing woody tissue. Moreover, shading seems to prevent the root systems of the seedlings from developing as well as those of seedlings grown without shade.

Omission of shade is necessary in the latter part of the season to induce the hardening of the tissues that makes dormancy more complete and renders the stock better able to endure the shock of being transplanted.

Shades are occasionally needed during very hot dry weather to prevent heat injury to seedlings that have begun to germinate but have not yet formed true bark on the stems, or to prevent retardation of growth. Exotic conifers are much more likely than native pines to require shades when grown in southern nurseries.

Burlap makes entirely too heavy a shade. Light cotton fabrics such as the cheesecloth or netting used over truck crops and tobacco might serve the purpose. The material most commonly used is lath or similar narrow strips of wood. These strips are nailed on light wooden frames, tacked to wires, or connected by means of wires interwoven around their ends. Each lath in the shade is separated from the next by a space equal to its own width, which gives 50 percent density. The shades are made the same width as the seed bed, and of any length desired; those on wooden frames are usually 10 or 12½ feet long, and those on wires 25 or 50 feet. Wire-mounted lath shades are particularly convenient because they can be rolled up from either end and can be picked up and carried by one man.

Shades are best supported on rails paralleling the edges of the beds and about 20 inches above them. These rails can be made of low-grade 1-by-3's or similar inexpensive material nailed to stakes. Shade frames are more effective against heat injury if they are high enough to permit good air movement under them.

WATERING

Nearly all the more successful of the large nurseries in the southern pine region use overhead sprinkler systems, the pipes of which rest in roller sockets on the tops of posts. Each line of pipe is rocked backward and forward in its roller sockets by a water motor, in such a way as to swing fine lines of spray back and forth over a strip 25 to 30 feet wide on each side of it. Several large nurseries use small rotary sprinklers or ordinary hose and spray nozzle, but without obtaining entirely satisfactory results. Several small nurseries water at reasonable cost and in sufficient quantity by means of hose. Irrigation in the paths was tried in one nursery, but was abandoned because too little water penetrated to the centers of the beds.

The quantity of water to be applied, and the frequency with which watering is needed, vary greatly with soil, rainfall, and number of hot, cloudless days. During any one week, rainfall and artificially applied water should ordinarily total at least as much as the average weekly rainfall of the locality in which the nursery lies. In a rainless week water equivalent to at least 1 inch of rainfall should be applied artificially, even though there have been abundant rains earlier in the season.

During germination the surface must be kept almost continuously moist, although preferably it should not be extremely wet. At other times, it is better to soak the nursery thoroughly at intervals of several days than to moisten merely the surface of the ground every day.

No authentic cases of injury to southern pine seedlings from watering in the daytime instead of at night have come to the attention of the Southern Forest Experiment Station. On the contrary, heat injury may sometimes be warded off by starting an overhead sprinkler during the hottest part of the day. Ordinarily, it is preferable to water at night, because the higher humidity and lower temperatures of night reduce the rate of evaporation and the water applied has a correspondingly greater chance to soak into the ground.

It is generally considered good practice, and in some nurseries in the most southern part of the region is essential, to stop all watering in August or September except in seasons of extreme drought. By August or September the seedlings should be so far advanced in development that a reduction of the water supply will not leave them too small for planting, but will merely cause the tissues to harden. Particularly on the better soils, reduction of the water supply toward the end of the summer is in some instances necessary not only to harden the stock but to keep it from becoming too large to plant economically with the tools ordinarily used.

WEEDING

From 4 to 7 weedings a year are necessary in even the cleanest of southern pine nurseries, and a dozen or more may be required where weeds are abundant at the start. The cost of hand weeding ordinarily makes up 20 to 40 percent of the total cost of 1–0 nursery stock.

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Certain general control measures reduce greatly the labor and expense of weeding even during the first year of application, and help still more to restrict the weed crop of the following season. Among the most important of these measures, particularly if the principal weeds are running grasses like Bermuda, is very thorough hand working of the seed-bed soil before sowing. Going over a bed thoroughly from end to end with a potato hook and then a rake takes less time than one hand weeding, and such a cleaning of the soil in advance of sowing may save half a dozen weedings.

If coco grass is present, working with spike-toothed or spring-toothed harrows to eliminate weeds does more harm than good because such harrows spread the bulbs of this particularly obnoxious weed. Bermuda grass and Johnson grass can be worked to the surface with toothed harrows; and as these weeds spread by rootstocks more than by seed, to destroy most of their overwintering rootstocks is more than half the battle.

Other general measures include late sowing, with one working of the soil before sowing to kill the weeds already started; drill sowing, to permit hoeing out some of the weeds and pulling the remainder by hand more easily than is possible in broadcast-sown beds; cutting weeds on the margins of the nursery and on surrounding land, to keep them from going to seed and scattering their seed over the beds; and growing heavy cover crops on portions of the nursery not being used for seedlings. It is important, also, to avoid bringing in from outside the nursery any soil or barnyard manure that may contain weed seeds, or using compost made of weeds that may have gone to seed before being pulled.

Aside from these measures, weed control depends largely on weeding by hand. To be effective, hand weeding must be done early and must be clean. The cost of early, clean, hand weedings, although sometimes very high, is almost invariably compensated for by a reduction in weeding costs later in the season and a great decrease in costs in following years.

Every man assigned to hand weeding must be taught never to weed on dry ground, never to break off weeds at the surface, and not to injure the seedlings in any way. He should not be allowed to break down the edges of the beds, or to rest his weight on his hands at any point within the bed. He should be taught to reach down to the weeds from above, instead of sliding his hands to them from the side among the seedlings.

Various devices such as knee pads, small stools, or benches, and hand tools such as small knives or teaspoon handles, make weeding easier and more efficient.

WEEDS PARTICULARLY SERIOUS IN THE REGION

The history of a dozen nurseries in the southern pine region indicates that crabgrass (*Syntherisma sanguinale* (L.) Dulac) and Bermuda grass (*Capriola dactylon*) are about equally wide-spread and troublesome. Coco grass (*Cyperus rotundus*), also commonly called nutgrass, although less common, is fully as serious in some nurseries and is perhaps the hardest of all to eradicate. Goosegrass (*Eleusine indica* (L.) Gaertn.) and crowfoot grass (*Dactyloctenium aegyptium* (L.) Richt.) are perhaps the next most important species. All other

grasses put together take a minor place. Except in a few nurseries, weeds other than grasses present relatively little difficulty.

Both Bermuda grass and nutgrass spread by means of creeping underground stems, reproduce from underground rootstocks or tubers, and are difficult to eradicate by pulling. The "nuts" of coco grass are readily killed by severe cold, and the rootstocks of Bermuda grass by cold and by drying. Plowing in the fall and leaving the land rough during cold weather greatly reduces the survival of plants of these two species, especially in the more northerly nurseries, and turning up Bermuda grass before a dry season is helpful. Geese eat the leaves of coco grass and thus help exhaust the food stored in the tubers, and can be allowed to feed on infested areas where soil-improving crops are being grown. Hogs eat the tubers, and can be turned into the nursery between lifting time and sowing time. Neither coco grass nor Bermuda grass can endure heavy shade; a heavy soil-improving crop, such as velvetbeans, in a season during which the soil is not occupied by pine seedlings should considerably reduce the numbers of both weeds.

CHEMICAL WEEDING

Zinc sulphate treatment, which has given good results as a method of weed eradication in other regions, has been tried on three different nursery sites for several years without satisfactory results. The chemical is inexpensive and easy to apply to the soil, and gives good control of weeds other than grass even when used in quantities so small as to cause little or no injury to any species of pine. The grasses, however, especially those that arise from rootstocks already in the ground, seem to resist it as successfully as the pines; and, since the grasses are the principal weeds in most southern nurseries, this renders the treatment generally useless. In nurseries in which the weeds of major importance are not grasses—particularly if the pines grown are longleaf and slash, which are more resistant to injury by the chemical—zinc sulphate should be tried. The chemical should be applied at the rates of 6 g, 8 g, and 10 g per square foot in small beds, preferably in two or more separate beds for each treatment. Check beds should be left between the treated beds and should be hand weeded; it might be instructive to leave one check bed entirely unweeded. Not until successful control of weeds has been demonstrated in the test beds, at reduced cost and without injury to the soil, should the chemical be applied to the nursery as a whole.

Weed killers applied to the foliage have not been tried in southern nurseries. Some of these, such as ferric chloride, roll off the leaves of grasses too soon to injure them, and consequently seem to offer little promise in such nurseries. Others, such as sodium chlorate solution, and acid solutions containing compounds of arsenic, may be expected to kill all plants on which they are sprayed, and are therefore unsuitable for application upon weeds growing among pine seedlings, whatever their usefulness in destroying patches containing weeds alone.

LATER PROTECTION

Between the end of the moist, cool weather of March and April and the onset of hot, dry weather, usually sometime in June, there

may be a slight lull in the activities of nursery pests. With the coming of summer, a new series of injurious agencies attacks the nurseries, the most harmful of which are usually insects, fungi, and drought.

INSECTS

Insects injurious to young southern pines may be grouped in three general classes. The first includes chewing or biting insects that feed on external surfaces of the plant. Many insects of this class, such as sawfly larvae and the adults of certain beetles, succumb readily to stomach poisons, such as arsenate of lead, applied to the plant. The second class includes sucking insects, such as aphids and scales, living on exposed surfaces of the plant but getting their food by thrusting slender mouth parts through the epidermis of the plant and sucking the inner juice. Insects feeding in this way are unaffected by stomach poisons on the outside of the plant, and can be controlled only by applying contact insecticides, such as nicotine sulphate or oil emulsion, to the insects themselves. The third class includes insects of several types that work underground or burrow within the tissues of the plant, out of reach of ordinary sprays. Examples are the adults and larvae of bark beetles, the larvae of pine tip moths, leaf miners of all kinds, and white grubs (May beetle larvae) working underground. In many instances, control of insects of this third class can be effected only indirectly, as by various cultural methods, or is entirely undeveloped.

Among the most persistent and destructive nursery pests, and likewise among the most difficult to combat, are the larvae of June bugs or May beetles (*Phyllophaga* spp.), commonly referred to by nurserymen as grubworms or white grubs. The exact life histories of the southern species of these pests are not known in every instance. In some regions it appears that the eggs are laid in the spring and that the larvae which hatch from them feed on dead vegetable matter in the soil until the following winter (*11*, *18*). In such cases, the larvae are small during this first year of their underground existence, and comparatively or entirely harmless to pine seedlings. Recent studies by the Bureau of Entomology and Plant Quarantine, however, indicate that in the South the larvae do not feed on dead vegetable matter the entire season, but become a menace to young pine seedlings. During their second year, after remaining more or less dormant through the winter at a considerable depth, they return to the top 6 or 8 inches of soil, the zone containing most of the feeding roots of the pine seedlings, and attack the roots voraciously. They feed throughout the summer and late into the fall, usually doing their most conspicuous damage during the hot summer months. Working singly or in groups, and moving back and forth in small tunnels, they cut off the seedling roots from 1 inch to 10 inches below the ground. The seedlings die in small patches, which increase in size and in irregularity as the grubs work outward from their starting points. Typical white grub injury is easily recognized by the color of the dying foliage, which changes from faded green to brown, and often by the patchy occurrence of the damage. The injured seedlings are easy to pull up, and show a characteristic pruning of the roots. If the roots are cut off 6 or 8 inches below

the surface of the ground they often heal over, and in that case the seedlings may recover and develop into satisfactory planting stock. Roots cut off 2 or 3 inches underground may begin to heal, but with the first water shortage the small quantity of moisture supplied by the reduced root system is exhausted and the seedlings die. Digging in the patches of injured or dead seedlings usually reveals one or more of the grubs. In general they are whitish in color, with hard brown heads and almost transparent abdomens, and bend double when disturbed. In addition to white grubs there may be present other forms which resemble these very closely but which are not injurious. This is apt to be the case where compost is applied to the soil. Information on methods of distinguishing these forms is obtainable from the Bureau of Entomology and Plant Quarantine.

It is rare for a nursery to be entirely free from white grubs. Even a light infestation may result in a steady drain on the nursery throughout the season, and a loss of 10 to 20 percent of the plants. When a heavy flight of adults has been followed by two seasons of weather favorable to the development of grubs, the grubs have destroyed as much as 60 percent of all the stock in a nursery.

No thoroughly satisfactory control for white grubs has been demonstrated in the southern pine region. Control by indirect or cultural methods should be applied whenever practical. These methods include locating the nursery as far as possible from pecan groves and hardwood stands and even from longleaf pines, on which the adults feed; avoiding establishment of the nursery on sites which have been in grass for more than one season, particularly without taking precautions to free the ground of white grub larvae; keeping beds, paths, and fallow areas as free as possible from vegetation during the flight of the adults in the spring, to make the ground less attractive for egg laying; practicing a rotation of crops; turning hogs or chickens into the nursery after the old stock has been lifted and before the new beds are sown, especially during plowing; and killing all white grubs found at any stage of cultivation, weeding, and lifting. More direct methods of control include the application of poison, both when the beds are made up and when damage becomes conspicuous.

In the Northeast and in Australia the application of 80 pounds of white arsenic (arsenic trioxide) per acre, in mixture with enough sand to make spreading easy, gave good control. Use of white arsenic in this manner in midsummer, followed by thorough wetting to wash the poison well into the soil, gave partial control in one nursery in Texas even after damage had become severe. A systematic trial of this method by the Southern Forest Experiment Station at Bogalusa, La., failed entirely. The Bureau of Entomology and Plant Quarantine reports it ineffective also in Nebraska and South Carolina, and, on the basis of recent investigations, warns against its use in certain light, sandy coastal plain soils until more is known about them lest severe damage to seedlings result and the site be rendered unproductive for a number of years.

The Bureau of Entomology and Plant Quarantine has tried arsenate of lead also in concentrations varying from one-half pound to 10 pounds per 100 square feet, for control of white grubs in seed beds of southern pine on several different soils in Maryland and the

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Carolinas. Some of the results have been unfavorable. The chemical not only injured or killed the seedlings grown on the soil immediately after the treatment but remained in the soil and, in all but the lightest applications, caused severe burning of the foliage of seedlings grown 1 or more years after the treatment.

Carbon disulphide emulsion applied to the surface of the soil has killed seedlings as well as grubs in three nurseries in which it has been tried. In one of these nurseries, a trial was made of carbon disulphide in liquid form poured into holes in the soil. Wherever the nurseryman found seedling tops wilting or fading he pulled 2 or 3 of the apparently injured trees. If their roots had been eaten by grubs he pulled all other apparently injured trees in the same spot, made a hole 2 inches deep with the end of a broom handle, poured in a teaspoonful of carbon disulphide, and plugged the hole with earth. This treatment seemed to succeed uniformly in stopping injury in the particular spots treated, and had no harmful effect on the trees.

Ordinarily less serious than white grubs, but occasionally far more dangerous to an individual nursery or block of stock, are cutworms. The different species appear and attack suddenly at various times of year. The worst attacks on record have occurred in midsummer. In one longleaf pine nursery more than a million seedlings were killed in approximately 1 week.

If discovered when they first begin working, cutworms are easy to control. A recommended method of control, as was stated earlier, is to prepare a bran bait according to formulae given in the appendix (p. 112) and scatter it through the nursery about sundown. The poison should be kept on hand at all times for use in emergencies.

Scale insects of the genus *Toumeyella* are another group of dangerous nursery pests. These are plump, grayish-brown scales the diameter of which varies from that of a small pencil lead to that of a BB shot or a little larger. Frequently their presence is marked by a sooty coating on the needles and stems of the infested seedlings. This coating is a harmless mold that grows on a honeydew exuded by the insects. The seasonal life history of the scale insects is not well known, but the rate of seedling development tends to confine their attack to the middle and latter part of the summer. Scale insects of the genus *Toumeyella* have been reported most commonly on slash and loblolly pines. So far as is known, they do not attack longleaf pine seedings in the nursery, although they have been found on the needles of naturally reproduced longleaf pines 3 or 4 feet high.

Prompt application of a miscible oil emulsion is effective in controlling scale. Miscible oils ordinarily can be obtained from dealers in seed, fertilizers, and gardeners' and farmers' supplies. These oils emulsify immediately upon contact with water, without heating or other special preparation, and therefore are simple and easy to use. They should be mixed and applied according to the manufacturer's or dealer's recommendation for summer (nondormant) sprays. If miscible oil cannot be obtained, kerosene emulsion (described in the appendix, p. 112) may be substituted fairly satisfactorily, although it is much less convenient to apply and must be made with great care lest it injure the foliage.

Seedlings infested with *Toumeyella* scale are useless for field planting. Although seedlings attacked by the scale may appear fairly healthy and although a late-season spraying may have freed them of the insects, because of loss of stored food or for some other reason practically all of them fail to survive transplanting. If the scale has been destroyed before the end of the growing season, however, and the trees have made some growth since the infestation came to an end, successful transplanting appears to be possible.

A pest somewhat less serious than the scale insects is the mite *Tetranychus telarius* L., the common red spider. Particularly during very hot, dry weather, this pest attacks pine seedlings and causes them to stop growing and turn yellow. The mites can hardly be seen without a magnifying glass. As adults they migrate by crawling rapidly. They spend the winter on the leaves of the common violet and other evergreen plants.

In localities where red spiders are abundant on agricultural crops, special care should be taken to keep the surroundings of the nursery as free as possible from plants with heavy foliage that remains green the year around. Red spiders are easily controlled by the use of bordeaux mixture, nicotine sulphate, one of the oil emulsions recommended in the foregoing for controlling scale, or dry sulphur. Either spraying or dusting should be repeated after an interval of 10 days or 2 weeks. The spray should be very fine and penetrating.

A conspicuous nursery pest, potentially serious but very easy to cope with, is the larvae of LeConte's sawfly (*Neodiprion lecontei* Fitch) (*21*). Other sawfly larvae attack southern pine nursery stock, but less commonly. Sawfly larvae resemble very closely the caterpillars of butterflies and moths, but differ from them in having 8 instead of 10 pairs of false legs (stubby, fleshy, unjointed appendages on the rear two-thirds of the body). They have a striking habit of rearing back, when startled, from the leaves on which they are feeding. Usually they feed in groups. Their bodies are greenish or yellowish, usually with rows of black dots along the sides, and their heads mahogany colored, brownish, or blackish. Like many other leaf-chewing insects, they are easily killed by means of lead arsenate (p. 112) or other arsenical sprays.

One or more species of *Tetralopha*, a soft-bodied moth the larvae of which live in a loose tube of webbing and frass, has appeared in nurseries in Florida, Mississippi, and Texas, and to a slight extent in Louisiana. It apparently does no serious damage, confining its feeding to a few needles on each tree. The Nantucket tip moth (*Rhyacionia frustrana* Comst.) (described on pp. 96–99) occasionally infests 1 to 5 percent of the slash and loblolly pine seedlings in a nursery, but does no appreciable harm. Other insects that have appeared from time to time in southern nurseries are various species of aphids, which can ordinarily be controlled with nicotine-sulphate spray (p. 112); grasshoppers, for which bran bait is recommended (p. 112); mole crickets, which can be poisoned by means of cottonseed meal and paris green (p. 111); and various species of mound-building ants.

FUNGI

The only serious disease of nursery stock so far encountered on southern pines is the brown-spot needle blight, caused by *Septoria*

acicola (Thum.) Sacc. (*25*). This is primarily a disease of longleaf pine seedlings. It occurs also on slash pine, particularly in nurseries that lie outside the natural range of the species or that are subjected to extreme drought. The first symptom is formation of small spots on the foliage. These spots soon develop into narrow brown bands, with definite margins, encircling the needles. The first signs of the disease are likely to appear in July or August, but infection may take place even in midwinter. Nurseries far removed from any infected stands of young longleaf pine seldom or never suffer seriously from brown spot. Infection is often heavy in nurseries in the immediate vicinity of infected young longleaf, and may take place very suddenly when weather conditions become favorable. A detailed study[10] by Verrall of spore production and dissemination during a period of nearly 6 months has indicated that slight infection takes place at considerable distances through the medium of windblown spores, but that serious infection is usually traceable to spores produced in fruiting bodies during prolonged warm rains and carried only so far as they can be spattered by rain.

Control of brown spot is simple, certain, and inexpensive. The infection is checked immediately by spraying with bordeaux mixture, lime-sulphur, or zinc sulphate-lime mixture, with casein or fish-oil soap as a spreader. Reinfection necessitates fresh sprayings, but there is no excuse for letting brown spot make any serious inroads in a nursery. From 75 to 85 gallons of bordeaux mixture or other fungicide should suffice for 20,000 square feet of seed bed. A man equipped with a 4-gallon knapsack pump can ordinarily spray this area in 8 hours, provided he does not have to walk an average of more than 300 feet to refill, or stop to prepare additional mixture.

OTHER NURSERY PESTS

Seedlings on very sandy soil, particularly on soil previously used for agricultural crops, sometimes become infested with nematodes. These cause knots on the roots and check growth almost entirely, soon causing an unhealthy appearance and high mortality. It is bad procedure to plant trees known to be hosts of the root-knot or other nematodes on land infested with these pests. Species or varieties of trees known to be immune to the nematode involved should be planted exclusively, or the land should first be cleaned of the pest. Treatments for nematodes are described in the appendix (p. 111).

"Salamanders", pocket gophers of the genus *Geomys*, tunnel and burrow through nurseries on sandy soils, throwing up little mounds of earth and destroying many seedlings by eating the roots. They are readily controlled by persistent trapping with any of the several kinds of burrow trap commonly found on the market, or by placing poisoned bait (p. 111) in the burrows.

DROUGHT

Extreme damage from drought takes the form of heavy mortality throughout the seed beds. Under milder drought conditions, conspicuous mortality is confined to the soils less retentive of moisture.

[10] VERRALL, A. F. INVESTIGATIONS OF SOME OF THE BIOLOGICAL ASPECTS OF THE BROWN-SPOT NEEDLE BLIGHT OF LONGLEAF PINE SEEDLINGS. U. S. Dept. Agr., Bur. Plant Indus. Manuscript report. 1933.

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Even moderate drought may cause considerable losses in a nursery by gradually killing a few seedlings here and there.

Failure of seedlings to make sufficient growth during the summer is another serious after effect of drought. This may make the stock partly or wholly unsuitable for planting, and thus not only result in waste of much of the money and effort spent on a nursery during the summer but delay seriously an entire planting program.

Visible drying of surface soil to depths exceeding 1 inch, particularly in the centers of the beds, is a sign of serious danger. When seedlings are very young, they sometimes show need of water by temporary wilting. At a later age they do not wilt visibly even when about to die from drought.

Aside from direct watering and the use of shade, already discussed, means of forestalling drought killing are reducing beds to the levels of the paths, terracing to prevent rapid run-off of rain water, increasing the organic content of the soil, adding loam or clay if the soil is very sandy, and growing the seedlings at relatively low density.

An after effect of drought that often gives the nurseryman warning to change his practice the following year is "troughing" of the beds, or markedly inferior development of the seedlings in the center of a bed as compared with those along the sides. The inequality in growth results usually from the fact that the border seedlings can draw on otherwise unused water in the soil included in the paths, in which case the nurseryman should provide more water for the beds and should decrease the seedling density unless it is already very low. Troughing may be caused also by impoverishment of the soil.

CHARACTERISTICS OF NURSERY STOCK

Longleaf pine seedlings, unlike almost all other tree seedlings, develop practically no stem during the period spent in the nursery. Their height is therefore no index to the success of the nursery treatment or to the fitness of the stock for planting.

Seedlings of slash and loblolly pine are typical of pines in general, except that they grow much more rapidly and vigorously than northern and western species. Shortleaf pine seedlings are somewhat smaller and usually have one conspicuous characteristic normally lacking in other pine seedlings, namely, a crook at the surface of the ground that causes the stem to arise at a point one-half to 1 inch away from the root collar. This crook must not be mistaken for a defect or the result of an injury. It in no wise lowers the grade of the seedlings; in fact, it is seldom lacking except in seedlings grown so close together that they are too weak and spindly for field planting.

The size of high-quality southern pine seedlings varies considerably with species. Within a species, also, it varies considerably from nursery to nursery and even from season to season in the same nursery. The size of seedlings is less important than their quality. Sizes and other stem and needle characteristics of grade 1 seedlings are discussed in the section on planting (p. 77). Characteristics of lower grade seedlings are discussed in that section (p. 79).

A properly developed nursery seedling has a root system proportionate to its top. Root development of nursery stock varies strik-

ingly among species of southern pines, however, and varies greatly within any one species according to the quality of nursery soil and the method of cultivation and watering. Longleaf pine usually has a strongly developed taproot, although on certain soils and possibly under other influences it develops a somewhat diffuse root system. Slash pine and occasionally shortleaf pine tend to have one or more rather strongly developed central roots, but in the main their root systems are much more fibrous and diffuse than that of longleaf pine. Loblolly pine usually has the most diffuse root system of the four species. Loblolly and shortleaf pines have the greatest quantity of absorbing roots in proportion to the top. Longleaf pine has a relatively meager supply of lateral roots, but in total bulk its root system is greater in proportion to the top than that of any of the three other species. The stout, thick-barked longleaf pine taproot is thought to be important as an organ for storing food. Slash pine has perhaps the most meager roots in proportion to the top of all pines produced for planting purposes in the United States. Its striking dissimilarity to other southern pines in top-root ratio is shown in table 15. It usually makes better height growth in the nursery than any of the other species, however, and survives well in the field.

TABLE 15.—*Height and ratio of top weight to root weight of 1-year-old nursery-grown seedlings of southern pines* [1]

Location of nursery and grade of oven-dry material	Longleaf pine		Slash pine		Loblolly pine	
	Needle length	Top-root ratio	Height	Top-root ratio	Height	Top-root ratio
Bogalusa, La.:	*Inches*		*Inches*		*Inches*	
Grade 1	14.2	3.52	8.4	5.50		
Grade 2	12.9	3.90	6.9	5.56		
Grade 3	12.8	3.24	5.1	6.17		
All grades	14.0	3.56	7.7	5.53		
Athens, Ga.,[2] all grades	14.1	1.38	7.3	2.95	5.5	1.42

[1] Small ratios, showing that roots are large in proportion to tops, theoretically indicate better quality of planting stock. Basis of table, in number of trees, as follows: Bogalusa nursery, longleaf pine, 67 grade 1, 14 grade 2, 2 grade 3; slash pine, 113 grade 1, 47 grade 2, 14 grade 3. Athens nursery, longleaf pine 50, slash pine 59, loblolly pine 88.

[2] MAY, J. T. See footnote 8, p. 46.

Although in the course of 10 months in the nursery individual roots of loblolly and shortleaf pines frequently penetrate to a depth of 20 inches and longleaf pine roots not infrequently go down 30 or 40 inches, most of the roots essential to the welfare of the seedlings are in the top 6 or 8 inches of the soil.

As the result of an apparently symbiotic relationship, known as "mycorrhizal", between the pines and certain soil-inhabiting fungi, minute fingerlike or clublike growths almost invariably occur on the roots of southern pine nursery stock. These growths, or mycorrhizae, are a combination of root and fungus tissues. They are most abundant, and reach their best development, on the best stock. In troughed beds, where the edges appear markedly higher owing to faster growth there than in the center, mycorrhizae are usually abundant on the border seedlings and almost entirely lacking on the stunted seedlings in the center. In seed beds surrounded by

partly decayed wooden curbs, frequently they develop in astonishing profusion and luxuriance on the roots in contact with the rotting wood. Most of these growths are white, but frequently those developing in contact with curb boards are yellow.

To summarize the normal course of development of nursery stock through the season, germination should be at its height not more than 3 weeks after sowing, and should be practically complete within a month or 5 weeks at the latest. Much more rapid germination frequently occurs and is greatly to be desired. By the time germination is complete, juvenile needles should be plainly evident in the seedlings that were first to free themselves from the seed coats. By early or middle May the cotyledons should have outlived their function as leaves and have given way to small but thrifty crowns of juvenile needles, that is, needles occurring singly. By the middle of June the juvenile needles of longleaf pine and the seedling stems of the three other species should have elongated considerably, and the tender epidermis should have given place to the first thin layers of real bark. Secondary, or fascicled, needles should begin to appear on longleaf pine seedlings early in July, and on seedlings of the three other species not later than the 1st of August. By the end of the growing season the secondary needles should have taken over the function of the primary needles almost entirely. When cold weather begins, stock of the very highest quality has no living primary needles left.

Characteristics of nursery stock as to dormancy are discussed on page 77.

Color changes other than the yellowing or browning caused by insects, disease, or drought sometimes take place with changes in season or in treatment. Slash pine frequently turns bronze-red or purplish bronze when struck by frost. In beds treated with fertilizers, stock has been observed to turn every color from orange to blue when the first frost came. Shortleaf pine often takes on a bluish purple tinge late in the fall, and loblolly pine sometimes changes color to a lesser extent; longleaf pine is the least likely to undergo such changes. These changes do not seem to be accompanied by the least change in the quality of the stock.

SUMMARY OF ESSENTIALS OF NURSERY PRACTICE

The first essentials of forest-tree nursery operation in the South are an adequate supply of water and a favorable site.

The usual sequence of nursery operations, and of dangers to nursery stock, throughout the year is somewhat as follows:

Late January through early February.—Plow, harrow, and make up the beds.

Late February through early March.—Finish making up beds, or freshen surface, and sow. Great danger of damage by birds. Beds must be kept moist during germination.

Middle to later March or early April.—Finish removing burlap cover from all species, or pine-straw mulch from longleaf pine. Danger of damage by birds until seeds have dropped from cotyledons. Danger of cutworm attack and damping-off. Possibly, first hand weeding.

Middle to end of April.—First, or possibly second, hand weeding. Still some danger from cutworms and damping-off.

Middle to end of May.—Second, or possibly third, hand weeding. At this period regular weekly watering may become necessary. (Watering may, of

course, become necessary earlier, and may be necessary at shorter intervals.) Some danger of heat injury.

June.—Third, or possibly fourth, hand weeding. Danger of heat injury.

July.—Probably another weeding. Possible danger of attack by cutworms and by red spider, especially during drought. Possible need of spraying in longleaf and slash pine nurseries exposed to brown-spot infection. Slight possibility that shade may be needed. Continued danger of heat injury.

August and September.—Watering usually needed through August, but preferably discontinued at beginning of September. Probably at least one weeding, much lighter than those earlier in the season. Possibly one or more sprayings to control scale insects. One or two sprayings for brown spot, if nursery is likely to be infected.

Middle to late November.—Earliest possible season for lifting.

Middle December to end of January.—Usual lifting season.

Continuing duties of the nurseryman include maintaining equipment, maintaining and if possible increasing the fertility of the nursery soil, and subduing the weeds. Addition of fertilizer, alternation of pine seedling crops with soil crops from season to season, and unremitting efforts to keep weeds from going to seed in or near the nursery, should be matters of course.

The nurseryman or a responsible subordinate should make at least a hasty inspection of the nursery once or twice a day. He should watch particularly for the first inconspicuous signs of drought, heat injury, cutworms, red spiders, scale insects, and brown spot.

COSTS

In nurseries in which only one species is raised at a time, under exceptionally good conditions as to personnel, climate, and soil, seedlings have been grown at a total cost of less than $1 per 1,000. The manager of one Gulf States nursery that produces approximately 1½ million trees a year quotes average costs, for 1928–30, of $1.50 per 1,000 for slash pine and $1.75 per 1,000 for longleaf pine. Smith (*28*), reporting on 5,204 acres of plantations established largely with stock grown by the company doing the planting, published figures indicating that 79 percent of this stock was grown at costs per 1,000 of from $1.06 to $1.22 only.

Other things being equal, nursery operation is very much more efficient if a large number of trees is grown than if a small number is grown. A nursery manager can exercise just as close supervision over a nursery producing 12 million or 15 million seedlings as over one producing 3 million seedlings, and general company overhead charged against the nursery can be reduced by distributing it over a larger output. Exceptions to this general rule are small nurseries maintained largely for instruction purposes at forest schools, and small private nurseries operated by farmers and other landowners in spare time.

Factors that increase costs far beyond those necessary for the species and site are the following: (1) Waste of seed, particularly through oversowing or through mismanagement resulting in incompleteness of germination. (2) Usurpation by weeds. Weeds must always be pulled before they go to seed, and for greatest efficiency should be pulled before they attain a height of 2 inches. (3) Inroads by birds, or attacks by insects such as cutworms, red spider, or scale. Heat killing. Drought killing. (4) Waste of motion.

Every operation carried out in the nursery, from plowing at the beginning to loading the stock in trucks at the end, involves many repetitions of a movement or series of movements which must be paid for at so many cents an hour. Nurserymen should constantly endeavor to reduce costs by simplifying processes, introducing labor-saving equipment, and abandoning useless treatment.

RECORDS

Successful operation of even the smallest nursery requires technical records. The details of nursery practices are too numerous to be trusted to memory, and written notes are necessary if the nurseryman is to make adequate use of his experience.

In large nurseries it is necessary to keep a detailed history of each lot of seed sown, each major treatment applied, and each compartment or soil block, together with a record of all costs. The records on seed lots are needed to determine suitability of individual strains for the site. The economy and usefulness of various procedures such as mulching, fertilizing, chemical weeding, and raising the level of beds cannot be determined without precise records of costs and results. A record of treatments given to any portion of the nursery soil is vitally important; for example, certain fertilizers must not be applied in rapid succession on the same soil lest they neutralize each other's effects or combine in a manner harmful to the plants. In a nursery operated by a business concern or a public agency, an itemized cost record is of course necessary as a guide in planning future treatment or expansion.

The following cost items should be kept separate: 1, Preparing the soil and making up the beds; 2, fertilizing; 3, mulch; 4, seed; 5, sowing (exclusive of 1 to 4 above); 6, protecting the beds from birds and removing the mulch; 7, weeding (total); 8, watering (total); 9, spraying (total, preferably itemized according to pests); 10, lifting; 11, equipment (initial cost plus cost of maintenance, prorated over expected life if equipment is to be used more than 1 year); 12, miscellaneous direct; 13, technical supervision by men other than those employed for nursery work alone (total); 14, shares of office or company overhead (prorated over items 1 to 13).

Either by means of small sample plots in representative beds or by means of periodic inventories of the entire nursery, the following data should be obtained each year for each species and principal treatment, as a guide in future operations:

1. Germination percentage of seed (for comparison with results of laboratory tests).

2. Number of trees still alive in May or June, expressed as percentage of seeds sown (as a guide in deciding how much seed to sow).

3. Average height and degree of development of the seedlings in May or June (as a guide in judging seedling development in later years).

4. Mortality between May or June and end of growing season (as a guide in efforts to reduce losses).

5. Mortality caused by any specific outbreak of insects or disease, or the like (as an index of the expenditure justified in combatting the pest).

6. Density of the stand at the end of the growing season (as an index of the effectiveness of nursery practice intended to produce a chosen density, and as an index of the effect of density on quality).

7. Average sizes, and percentages of different grades, of seedlings at the end of the growing season (as an index of effectiveness of methods and maintenance of soil fertility).

8. Total output exclusive of culls (as a basis for computing costs, planning plantations, and reporting production).

For recording unmistakably the results obtained in a nursery study, photographs of the deciles of a representative sample of the seedlings grown under any given conditions have proved excellent. A sample consisting of 100 or some other suitable number of seedlings is lifted and the seedlings are arranged in order from best to poorest. The arrangement is made by eye, but is checked as carefully as possible, preferably by more than one worker. The 9 seedlings that divide the array into 10 equal parts (if 100 are taken, the tenth, twentieth, and so on) are then separated from the lot, arranged in order against a ruled background, and photographed. It is well to include in the photograph a label unmistakably identifying the conditions under which the seedlings have been grown.

Usually it pays in the long run to have the man in charge of the nursery keep a daily journal of work done, of interesting developments, and of decisions reached concerning future practice.

It is an excellent plan to keep a photographic record of the nursery, including several series of well-selected views taken from fixed points, a series showing all regular nursery operations, and examples of whatever damage is done by nursery pests. A series of photographs of the deciles of representative lots of stock will form a valuable basis of comparison for stock raised in later years.

PLANTING

SITES AND SPECIES

In artificial reforestation in the southern pine region selection of the site to be planted and of the species to be used depends primarily on the forest type originally occupying the land, logging and fire history and subsequent natural reseeding, soil conditions, the presence or absence of various brush species, and the suitability of the different southern pine species[11] for the site and for available markets.

As has been seen in figure 1, the range of slash pine is the most limited, and that of shortleaf pine the greatest. Longleaf pine is widely enough distributed to fill most of the region's planting needs, and slash pine seems to be able to thrive considerably beyond its natural range and hence to be almost as widely available.

By far the greater part of the area needing forest planting in the South was formerly occupied by pure or nearly pure stands of longleaf pine. Several million acres of land formerly occupied by longleaf pine appear to be incapable of restocking naturally with any useful species in less than 40 years (*32*).

[11] Results of efforts at reforestation with exotics in the southern pine region are discussed in the appendix, p. 113.

Under present conditions much of this nonrestocking longleaf pine land cannot profitably be planted, because of poor soil quality or because of dense stocking with scrub oak and other undesirable species. Among the least favorable planting sites are those on which the soil consists of deep, coarse sand, very low in fertility and in capacity for holding moisture. Such sandy soils occupy extensive areas in western and central Florida, south-central North Carolina, and central South Carolina.

Over most of the nonrestocking longleaf pine areas of better quality the soils consist of a comparatively shallow stratum of fine sand or sandy loam overlying a stratum of rather stiff sandy clay. Such soils are classified as sandy loams. They have high moisture-holding capacity and considerable fertility, but they bake hard in dry weather and their subsoil seems to be too stiff to favor loblolly pine. On such lands longleaf pine thrives and slash pine gives promise of making excellent growth at least where the temperature and rainfall resemble those of its natural range. Such lands are not in great demand for agriculture.

Characteristic loblolly pine areas on which there is occasion for planting occur on the sandy coastal plain from South Carolina north to Maryland and in the piedmont area from Mississippi east to Georgia and thence northward into North Carolina. A large proportion of these areas do not appear to offer satisfactory growing conditions for slash pine, which grows less rapidly when planted far north of its native range and is subject to windthrow in regions of occasional sleet and snow. The areas on which loblolly pine should be planted are in many cases abandoned agricultural lands, often more or less eroded. Areas of that description outside the natural range of loblolly pine offer opportunities for planting shortleaf pine; these include some of the most badly eroded lands in the Eastern States, and much abandoned agricultural land toward the western edge of the pine belt, as in Arkansas and eastern Texas, where the rainfall is apparently too low for pine species other than shortleaf.

In the Georgia and Carolina piedmont areas, and especially in the silt loam uplands of northern Mississippi, abnormal soil erosion is widespread and appears to be accelerating. Of the millions of acres of land so affected, practically all should never have been cleared and practically all has been farmed injudiciously. Rainfall is heavy, frost action extremely severe, surface soil highly susceptible of washing, and subsoil highly subject to undercutting by frost and rain. Control methods include forest planting, preceded by plowing of gully banks and construction of check dams. The species preferred for this special purpose include black locust, shortleaf pine, and loblolly pine. Directions for erosion-control planting are available in several publications (*19*, *20*, *33*).

Other things being equal, among areas in need of planting those of highest potential productivity should be planted first. Land that gives promise of prompt natural restocking with species of possible commercial use and with stands of adequate density should be saved for the last, except under unusual circumstances.

Ordinarily, it is desirable to plant clear land before brushy land. It may be advisable to make an exception of brushy land, incapable of restocking naturally with valuable species, where pines, if planted

promptly, could get ahead of the scrubby hardwoods. A system called "skeleton planting" (*29*) has been suggested to combine production of merchantable timber with improvement of deteriorated sites occupied largely by nonmerchantable species. This consists in planting 200 or 300 trees of the desired commercial species per acre, in natural openings or on apparently favorable patches of soil. The cost per acre for planting stock is low, cultural methods such as liberation cuttings or prunings are concentrated on the few stems intended for the final crop, and the cost of early thinnings, such as must sometimes be made without profit in young stagnated pine stands, is avoided. Under this system, which has not yet been tried in the South, the natural succession of subordinate species continues to improve soil conditions and the crop trees put on wood of superior quality. That the method is desirable for the southern pines is indicated by the results frequently observed in natural stands in which loblolly and shortleaf pine have grown in mixture with hardwoods and in slash pine plantations established by ordinary planting methods in heavy oak brush.

In general, the best species to plant on a given site is the species that made up the bulk of the original stand. If for any reason this species is undesirable, or if conditions resulting from logging, fire, or the encroachment of brush make use of the original species inadvisable, it is best to use a species known to grow well on similar soils nearby. For example, slash pine often succeeds on brushy cutover longleaf pine land on which, because of the shade cast by the brush, the initially slow-growing longleaf pine would have little chance of success.

Other things being equal, the species chosen for planting should be that promising greatest resistance to insect or fungous enemies likely to cause trouble in the locality. For example, longleaf or slash pine should be planted instead of loblolly or shortleaf pine in localities where damage by Nantucket tip moth is severe. Another element in choice of species for site is comparative fire resistance, discussed on pages 94 and 95.

OUTSTANDING SPECIES CHARACTERISTICS

Of the four principal southern pine species, longleaf and slash produce the heaviest and strongest wood. Slash pine produces naval stores somewhat more abundantly than longleaf (table 2). Slash pine grows more rapidly than longleaf, and, for the first 25 to 30 years, faster than either of the two other principal species (table 1).

Loblolly pine produces wood less valuable than that of longleaf and slash pine or than that produced by shortleaf pine where the latter reaches its best development. It grows more rapidly, however, than any of the other southern pines in rotations up to 60 years. Its wood makes excellent pulp. In this respect both loblolly and shortleaf pine excel longleaf and slash pine under the methods of pulp manufacture thus far put into practice. The higher resin content of slash and longleaf pines places them at a certain disadvantage in the manufacture of kraft-paper pulp.

Slash and loblolly pine are the easiest to raise in the nursery; according to our present knowledge, longleaf pine is next. Slash is the easiest of the southern pines to plant, followed by longleaf.

In adaptation to different sites and ability to endure unfavorable conditions in the field, high-quality longleaf pine stock clearly stands first. In this respect slash pine bids fair to take second place, at least aside from climatic limitations. Less is known about shortleaf pine, but it seems to be adaptable to a greater variety of soils than loblolly pine.

MIXTURE OF SPECIES

Establishment of pure even-aged stands of large extent has proved a serious mistake in the case of loblolly pine, and is thought inadvisable in the case of the three other species. Mixed planting is desirable for four different reasons. (1) In the present state of uncertainty as to which species is best for any particular site mixed planting has, on the average, a much better chance of establishing a fully stocked and productive stand than single-species planting. Variations in soil and drainage cause differences in site quality within comparatively short distances. (2) Mixture of species reduces the danger of rapid spread of insect infestations or disease epidemics, and can guarantee to some extent the survival of a fair stand in any of the numerous cases in which the insect or fungus attacks one species only. For example, if slash pine is planted in mixture with loblolly pine tip-moth attack is less likely, because the slash pine is not a favorable host for the moth, and if the insect does attack the loblolly pine and destroy its value the slash pine can still form a full, healthy stand. (3) Mixture of species may lessen the potential fire damage; in particular, longleaf pine is desirable for planting in mixture with slash or loblolly pine even on a site where one of the latter species is most likely to yield a large financial profit, because after its first growing season in the field longleaf is much more resistant than the three other species to fire. (4) As years go by changes in demand or other market conditions may make a once popular species less profitable, with the result that a second species will advance in favor.

Two species planted in mixture may alternate by rows, or may alternate within each row. In planting slash pine and longleaf pine in mixture it is well to alternate three rows of the one species with three rows of the other, because slash pine makes so much more rapid growth than longleaf pine at the start that if single rows are alternated it is likely to overtop and suppress the longleaf pine between the fifteenth and twentieth years in the field.

SPACING

The choice of a spacing at which to plant a given species of southern pine is almost as important as the choice of species for a given site. It may affect the cost of establishing the plantation and the quantity and quality of lumber produced, and hence the profit from the first rotation, even more than choice of species.

The southern pines are relatively intolerant of shade. With the exception of longleaf, in even-aged pure stands they tend to grow uniformly in height. For these reasons, very close spacing of species other than longleaf is likely to result in stagnation soon after the crowns close.

Pure even-aged stands of longleaf develop very irregularly in height [12] from an early age. The contrast in height growth between both planted and natural stands of longleaf pine and planted stands of other species is shown in figure 9. The contrast in this respect between planted longleaf pine and planted loblolly pine is illustrated in figure 10. Because of the tendency of the species toward early differentiation in crown class, at any spacing the danger of stagnation is less for longleaf pines of a given dominant height than for other pines of that height. Hence a close spacing might be permissible for longleaf pine when it would not be so for the three other species because of the prospect that thinning would be economically impracticable.

The southern pines' remarkably rapid growth insures that even when spaced rather widely they will close their crowns at an early age and thus prune themselves naturally. Wide spacing has the fol-

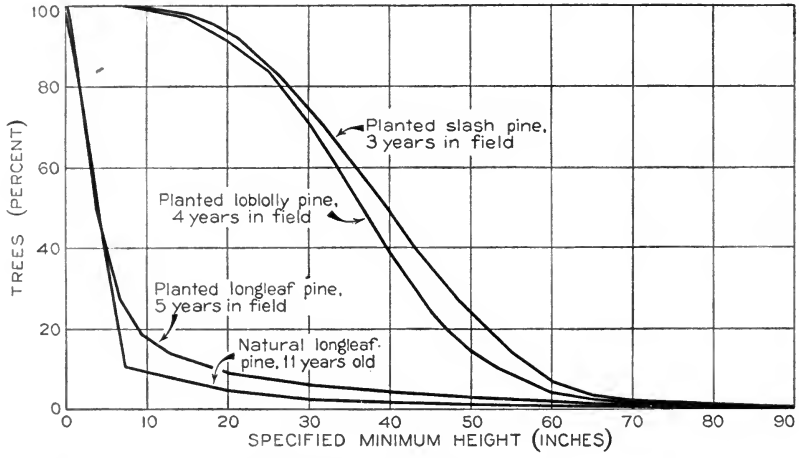

FIGURE 9.—Relative height distribution of planted and naturally reproduced longleaf pine and of planted slash and loblolly pine. (Basis, measurement of the following numbers of trees: Planted longleaf pine, 1,850; naturally reproduced longleaf pine, 2,168; slash pine, 2,778; and loblolly pine, 823.)

lowing principal advantages: (1) It reduces the cost of establishing the plantation. Cost of planting stock is reduced in direct proportion with number of trees planted per acre, and cost of labor involved in planting is reduced in a lower but considerable proportion. (2) It reduces the need of very early thinning to prevent stagnation, and frequently makes it possible to postpone the first thinning until the trees to be removed are large enough for pulpwood or other merchantable products. (3) It results in rapid diameter growth. If this can be brought about without sacrificing quality, it means earlier yield of merchantable products. Rapid diameter growth is especially important in plantations established for naval-stores production, since (as is shown in table 2) yield of gum increases with increase in diameter.

[12] A few plantations of longleaf pine almost as uniform in height growth as slash pine have been observed in South Carolina. All available evidence indicates that this unusual uniformity in height growth is the result of using vigorous stock very skillfully graded by the method described on p. 79.

Close spacing has these advantages: (1) It raises the quality of the product by causing earlier self-pruning, smaller knots, better recovery from attack of such insects as tip moth, and, usually, superior grain. (2) It decreases the probability that replacements will be needed.

Striking differences in habit of growth, together with differences in the purposes for which they are grown, make the southern pines differ somewhat as to space requirements in young plantations. Figure 11, based on drawings, to scale, of representative trees in plantations 7 to 10 years old illustrates essential differences in habit.

Longleaf pine and slash pine are sparsely branched. As trees of these species increase in height the lower branches weaken, die, and rot off before attaining any great size. The greatest crown width tends to move upward rapidly. Sidewise extension of the crown (marked by pairs of short lines at the bases of the trees in fig. 11)

FIGURE 10.—Planted longleaf pine (left) and loblolly pine (right) after 8 years in the field. The loblolly pines are approximately even in height, whereas more than half the longleaf pines have not yet emerged from the grass.

is decidedly moderate. Both longleaf and slash pines usually are entirely free of deformation resulting from insect attack and accordingly have straight main stems. Loblolly and shortleaf pines have more numerous branches, and after Nantucket tip-moth attack their branches subdivide prolifically. The lower branches not only persist longer than those of longleaf and slash pine but continue to grow vigorously, making large knots in the wood and producing the broad, somewhat conical crown shape shown in figure 11. The main stems of loblolly and shortleaf pine are frequently deformed as a result of tip-moth attack. Because of the habits of growth just described it is desirable to grow loblolly and shortleaf pines at somewhat closer spacing than longleaf and slash pines. The fact that loblolly and shortleaf pines are preferred for pulpwood, and that longleaf and slash pines are of value for naval stores as well as for wood products, is an argument in the same direction.

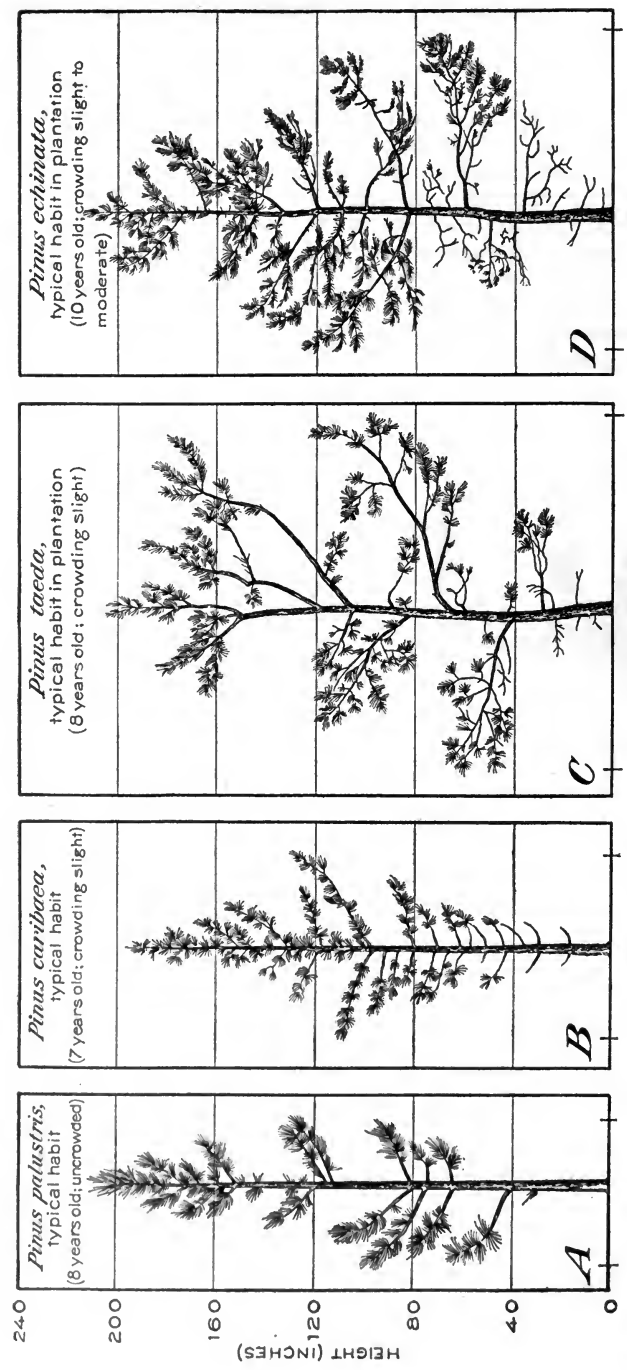

FIGURE 11.—Longleaf (*A*), slash (*B*), loblolly (*C*), and shortleaf (*D*) pines typical in form and branching habit of stock 7 to 10 years in the field. The longleaf and slash pines grew practically without crowding and the loblolly and shortleaf pines were crowded only slightly to moderately.

In an experimental planting of loblolly pine established in 1923, trees spaced 5 by 5 feet or 6 by 6 feet have tended during the first 10 years in the field to develop better form, with smaller knots, finer grain, and better recovery from tip-moth injury, than trees spaced 8 by 8 feet. The differences in spacing have had no significant effect on height growth. The plantation was established with 1–0 nursery stock on a site relatively poor for the species. Details of the results are given in table 16, and the plantations spaced 5 by 5 feet and

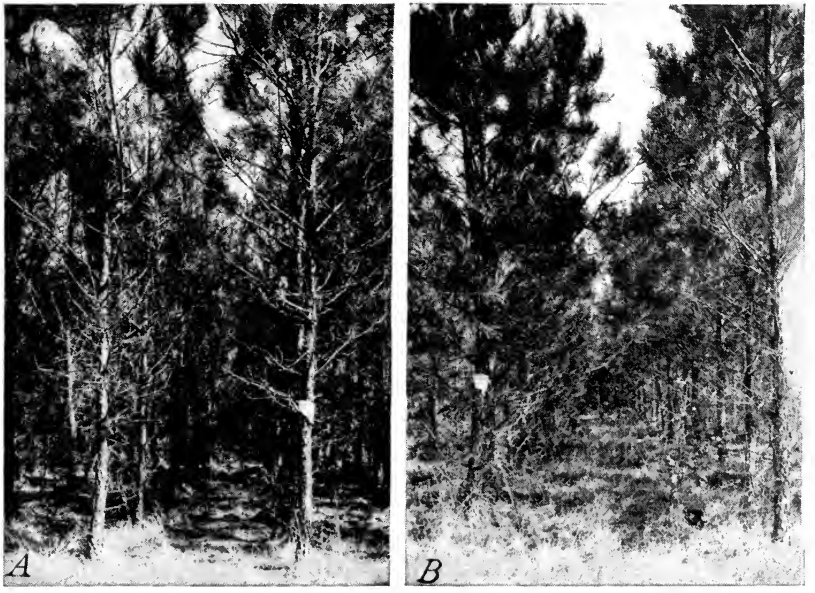

FIGURE 12.—*A*, Loblolly pine planted at spacings of 5 by 5 feet, 10 years after planting; *B*, loblolly pine planted at spacings of 8 by 8 feet, 10 years after planting.

8 by 8 feet are shown in figure 12. Practically no other systematic experiments to show the effect of spacing upon southern pines have been completed.

TABLE 16.—*Development of loblolly pine planted at different spacings, during its first 10 years in the field*[1]

Item	5 by 5 feet	6 by 6 feet	8 by 8 feet
Height.....feet	20.96	19.66	19.91
Diameter breast high.....inches	3.39	3.54	4.02
Crown diameter.....feet	6.45	6.94	8.41
Distance from ground to lowest live limb.....do	7.14	5.58	4.62
Portion of total height below lowest live limb.....percent	34.06	28.38	23.20
Recovery from tip moth injury[2].....	2.79	3.40	3.56

[1] Figures presented are averages based on 600 trees, of which 200 were selected at random from the interior of each of three 1-acre blocks planted at the 3 spacings, respectively, on Ruston fine sandy loam near Bogalusa, La. The plantations were established in February 1923.
[2] 1=good recovery; 3=medium recovery, and 5=poor recovery.

In the southern pine region a very great part of the forest planting has been done not in the "square" spacings (6 by 6 feet, 8 by 8 feet, etc.) customary elsewhere but, with some slight irregularities, in rectangles, usually 6 by 8 feet.

Table 17 gives suggested spacings for southern pines under the conditions ordinarily encountered. The reasons for these spacings are fairly obvious. Where anticipated pulpwood production promises profitable thinnings or where thinning operations are contemplated as a part of the undertaking, spacing should be somewhat closer than where timber production cannot count on thinnings. Loblolly and shortleaf ordinarily may be spaced closer than longleaf and slash. For naval stores production, light and ground space are prerequisite. Where timber of good quality is to be the main crop and naval stores secondary, moderately close spacing is preferable even though it somewhat reduces the yield of naval stores.

TABLE 17.—*Suggested spacings at which to plant southern pines of various species, by intended use of plantations*

Species	Intended use	Suggested spacing	Species	Intended use	Suggested spacing
		Feet			*Feet*
Longleaf and slash	Timber production without thinnings.	6 by 8 7 by 7 8 by 8	Loblolly and shortleaf.	Timber production without possibility of early thinnings.	6 by 6 7 by 7
	Combined timber and pulpwood production.	6 by 6 6 by 8		Timber or timber and pulpwood production with probability of early thinnings.	5 by 5 6 by 6
	Naval stores production.	10 by 10 12 by 12		Erosion control	3 by 3 4 by 4

In "skeleton planting", discussed on page 68, the spacing would, of course, be not only irregular but also very wide, perhaps equivalent to a regular spacing of from 12 by 12 feet to 20 by 20 feet.

SITE PREPARATION

It has become increasingly common to plant southern pines without any direct preparation of the planting site. On some soils and in some cover types it is desirable to plow shallow furrows in which to set the trees. Plowing is particularly desirable on areas where the growth of grass is so luxuriant that it threatens to smother planted seedlings during their first summer in the field. It is likewise advisable on extremely dry, sandy sites, on which a slight furrow may serve to concentrate moisture. When a horse or team is used in plowing a middle breaker or a "scooter stock" is preferable to a turning plow unless longleaf pine is to be planted. If the middle breaker is used the furrows are less likely to require additional hand clearing with the planting tool, but more of the turned-out soil washes into the furrows and this "silting" tends to cover the bud of the stemless longleaf pine seedling and either kill the tree or delay the beginning of height growth. Where tractor plowing is feasible, satisfactory results can be obtained with a disk plow set to cut a very broad and shallow furrow. Furrowing, at 8-foot intervals, increases planting costs by from 5 to 15 percent; Smith (*28*) records an average of 32.4 cents per acre for 5,204 acres.

As a method of preparing a site for the planting of longleaf pine, clearing the grass from spots 12 to 15 inches square by means of heavy hoes is more satisfactory than plowing furrows. The spots should

be hoed during the summer, so that fall rains will wash in any loose soil and cause it to reach a permanent level before the planting season arrives. Longleaf pine seedlings properly set in such spots suffer little or no damage from "silting."

Either a plowed furrow or a hoed spot should be made as shallow as possible without leaving grass or other vegetation in it with sufficient roots to start new growth.

Some experiments have been made on adverse sites with plowing all over instead of in strips. In some instances the plowing has been followed by harrowing. Such treatment breaks up the native vegetation enough to prevent its competing seriously with the planted stock, and sometimes insures success where ordinary planting methods would fail; but its cost is entirely too high for general use. Where planting requires such thorough preparation, ordinarily it should not be attempted.

Sometimes it is necessary to clear land of brush either before planting or shortly after planting. The principal species to be cleared are usually oaks—blackjack, southern red, blue-jack, and post oak on the so-called sandy loam soils with a stiff sandy clay subsoil, and turkey oak and blue-jack oak on the deep sands. All these species sprout vigorously and even if cut in August or September may regenerate a dense cover from 12 to 24 inches high before cold weather sets in. If slash or loblolly pines can become established successfully under brush and grow a little under it in the first 2 years following planting, it is better to cut the brush after planting instead of before, because the pines take on a new lease of life when liberated and thereafter stay well above the oaks. If the brush cover is so dense that there is doubt of the pines' surviving under it, it is better to cut the brush before planting and if need be to return 2 or 3 years after planting to cut the sprouts actually interfering with the pines. On very brushy land, advantage should be taken of natural openings regardless of the resulting irregularity of spacing.

To plant longleaf pine under brush of any great density appears unwise. If the brush is cleared either at the time of planting or 2 or 3 years later, there is little or no chance that the pine will escape being overtopped by the resulting sprouts. If, on the other hand, the brush is left undisturbed until the pine has reached an age at which it ordinarily makes good height growth, there is serious danger that the shade cast by the brush and the competition of its roots for water and nutrients will entirely kill out the pine.

Burning of the planting site in advance of planting has often been advocated to facilitate planting by clearing the ground, to decrease vegetative competition with the young seedlings, and to transform the whole area into a sort of firebreak for the first season following planting. Such burning undoubtedly makes work easier for the planting crews if too long a rainy season does not intervene between burning and planting; but heavy or protracted rains harden the soil on burned areas more than on those protected by a cover of plants and litter. Evidence concerning the effect of fire on the chemical and physical condition of the soil is conflicting and inconclusive,[13]

[13] DEMMON, E. L. FOREST FIRES IN THE SOUTH. U. S. Dept. Agr., Forest Serv. Unpublished manuscript.

but burning the surface vegetation certainly increases sheet erosion, and this in the case of longleaf pine seedlings adds to the danger of injury to the trees from silting. Cattle tend to concentrate on burned areas in the spring and sometimes cause damage by trampling; and burning leads to more nipping of planted stock by sheep and goats. Except under extraordinary circumstances, therefore, burning of the planting site cannot be recommended. Several thousand acres of thrifty longleaf pine plantations show plainly that success does not depend on the use of fire at the time of planting.

SEASON AND WEATHER

To be consistently successful at reasonable cost, planting must be done during the dormant season. In the Gulf States this practically limits it to December and January, although early cold weather makes November planting possible in some years and a delayed spring sometimes makes it possible to work well into February.

In the more northerly part of the southern pine region freezing weather breaks the planting season into two parts. Although experiments in the Gulf States show a slight superiority of early planted over late planted stands both in survival and in height growth, especially for slash pine, farther north the latter part of the season appears to be preferable because of the danger of frost-heaving of stock set in the field before the midwinter freezes and thaws.

Certain skillful tree planters of the Gulf States prefer to postpone planting until at least one sharp frost or good freeze has "hardened" the stock in the nursery.

At least two instances have been recorded of successful planting of slash and loblolly pine in the spring, when the tops had put on 2 or 3 inches of growth and root development had reached a state of great activity. Great care was taken to keep the stock wet, and the planting was followed by very favorable weather. In the main, it is not wise to handle stock after growth has started in the spring.

The Southern Forest Experiment Station has no records of successful planting of southern pines during the summer on a scale and in a manner suitable for reforestation.

The Carolinas, Georgia, and Florida are likely to have a period of relatively low rainfall in October and November and another in April, with only a moderate increase during the midwinter months. The Gulf Coast States other than Florida are more likely to have only a very moderate rainfall deficiency in October and then to have distinctly heavy precipitation in February and March. Thus in the Gulf coast region west of Florida, as compared with the region to the east, the planting season is less likely to be delayed by fall drought and there is more likely to be plenty of moisture to help the newly planted trees get a good start in the beginning of their first growing season in the field. Favorable conditions of winter and spring rainfall ordinarily occur as far west as the third or fourth tier of Texas counties west of the Louisiana boundary. It must be emphasized that the general relationships just outlined by no means always hold true. The entire region is notably subject to droughts at almost any season.

Prolonged drought is the climatic factor most to be dreaded in connection with reforestation with southern pines. Fall droughts

sometimes leave planting sites so dry and hard that planting is impossible when the stock becomes dormant and must be postponed until the soil is softened by early winter rains. Drought during the usual planting season may make it necessary to postpone planting until dangerously close to the beginning of the growing season. Severe drought early in the growing season is to be dreaded most of all, because it catches the trees before they have had time to establish their root systems in the new environment and they lose water by transpiration faster than the roots can supply it. Spring droughts result in high mortality.

Planting in cloudy or even rainy weather is more likely to succeed than planting in clear and particularly in clear windy weather. Lack of sunshine and presence of considerable quantities of moisture in the air are helpful in keeping the roots of seedlings from drying out during planting. Rainy weather also insures sufficient soil moisture.

Warm weather has a tendency to bring seedlings out of their dormancy and thus decrease the likelihood of their survival. Very cold weather makes work more difficult, thus unduly increasing planting costs or seriously reducing survival. Instances have been reported in Louisiana and eastern Texas of slash pine being killed by freezing of the roots during planting.

STOCK

GRADES

At the end of the first growing season grade 1 seedlings of slash, loblolly, and shortleaf pines, as defined by the grading system devised by the Southern Forest Experiment Station, have greater average height than grade 2 or 3 seedlings of those species. (A few grade 2 seedlings may be taller than part or even all of the grade 1 seedlings.) Grade 1 seedlings of slash pine are ordinarily from 10 to 16 inches high, those of loblolly pine from 8 to 14 inches high, and those of shortleaf pine from 6 to 12 inches high. Development, rather than size, however, is usually the determining factor in grading. Grade 1 seedlings of these three species have stout, woody stems with well-developed bark. Their foliage consists largely or entirely of secondary (fascicled) needles. Winter buds are well developed on a large percentage of them, unless an unseasonable warm spell has caused the buds to open and a little new wood to form. Such new growth may become dormant in its turn and a second, somewhat less heavily scaled winter bud develop. Seedlings developing in this way are not quite so desirable as stock that remains dormant all winter, but with reasonable care can be planted as successfully as any others.

Grade 3 seedlings of slash, loblolly, and shortleaf pine have weak, slender, succulent stems, sometimes almost wholly lacking in true bark. Except in rare instances the foliage consists entirely of juvenile (single) needles. Winter buds are never present. At least in the southern part of the Gulf Coastal Plain, grade 3 stock does not become dormant, but continues to grow practically throughout the winter.

Grade 2 seedlings may have fairly stout stems but no fascicled needles, or a few fascicled needles but poorly developed stems.

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Winter buds are more likely to be lacking than either secondary needles or satisfactory stem development. Such seedlings are less likely to continue growth throughout the winter than those of grade 3, but may not attain the complete dormancy ordinarily characteristic of grade 1 stock.

Seedlings of longleaf pine cannot be graded on the same basis as those of the three other species, since they develop practically no stems while in the nursery. Grade 1 longleaf pine seedlings have vigorous and abundant fascicled needles 10 or 12 to 18 inches long. They have very thick, stout taproots, usually from three-sixteenths to one-half inch thick at the surface of the ground. In ordinary seasons a high percentage of grade 1 longleaf stock has winter buds covered by well-developed white or brownish scales. Grade 3 longleaf pine seedlings are small, with few if any fascicled needles and with short primary needles. The taproots are very slender at the surface of the ground and buds are wholly lacking. On grade 2 longleaf seedlings the foliage is ordinarily fairly vigorous and may contain secondary needles up to 15 inches in length, but the needles are neither so abundant nor on the average so long as those of grade 1 stock. The taproots are not so thick as those of grade 1 stock. Buds covered with scales are generally entirely lacking, but a relatively high percentage of grade 2 stock may have naked buds consisting of very short needle tips closely packed.

The characteristics of the different grades are summarized, species by species, in table 18. Seedlings of various grades and species are shown in figure 13, *A*, *B*, *C*, and *D*.

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TABLE 18.—*Characteristics of southern pine seedlings of different grades*

Grade no.	Usual heights[1]	Stems	Bark	Needles	Winter buds	Remarks
			LONGLEAF			
1	12 to 18 inches	3/16 to 1/4 inch in diameter at surface of ground.		Abundant. Largely or entirely fascicled.	With scales usually abundant.	Usually become completely dormant.
2	Intermediate between those of grades 1 and 3.	Diameters at surface of ground intermediate between those of grades 1 and 3.		Intermediate	Scales usually lacking; naked buds usually abundant.	In Gulf States, dormancy depends on weather conditions.
3	6 to 8 inches	Very slender at surface of ground.		Scanty	Never present	Rarely dormant in Gulf States.
			SLASH			
1	10 to 16 inches	Stout, woody	Well developed	Largely or entirely fascicled.	Usually well developed	Usually become completely dormant.
2	Mostly less than those of grade 1.	Spindling to moderately stout.	Moderately developed.	Few or none fascicled	Seldom present	In Gulf States, dormancy depends on weather conditions.
3	All less than those of grade 2.	Spindling, succulent	Sometimes little developed.	Usually none fascicled. Bluish in color.	Never present	Rarely dormant in Gulf States.
			LOBLOLLY			
1	8 to 14 inches	Stout, woody	Well developed	Largely or entirely fascicled.	Usually well developed	Usually become completely dormant.
2	Mostly less than those of grade 1.	Spindling to moderately stout.	Moderately developed	Few or none fascicled	Almost never present	In Gulf States, dormancy depends on weather conditions.
3	All less than those of grade 2.	Spindling, succulent	Sometimes little developed.	Usually none fascicled. Bluish in color.	Never present	Rarely dormant in Gulf States.
			SHORTLEAF			
1	6 to 12 inches	Stout, woody	Well developed	Largely or entirely fascicled.	Usually well developed	Characteristic crook at surface of ground. Usually become completely dormant.
2	Mostly less than those of grade 1.	Spindling to moderately stout.	Moderately developed.	Few or none fascicled	Almost never present	Crook usually present. In Gulf States dormancy may or may not occur, according to weather conditions.
3	All less than those of grade 2.	Spindling, succulent	Sometimes little developed.	Usually none fascicled. Bluish in color.	Never present	Crook often lacking. Rarely become dormant in Gulf States.

[1] In the case of longleaf pine seedlings, needle lengths.

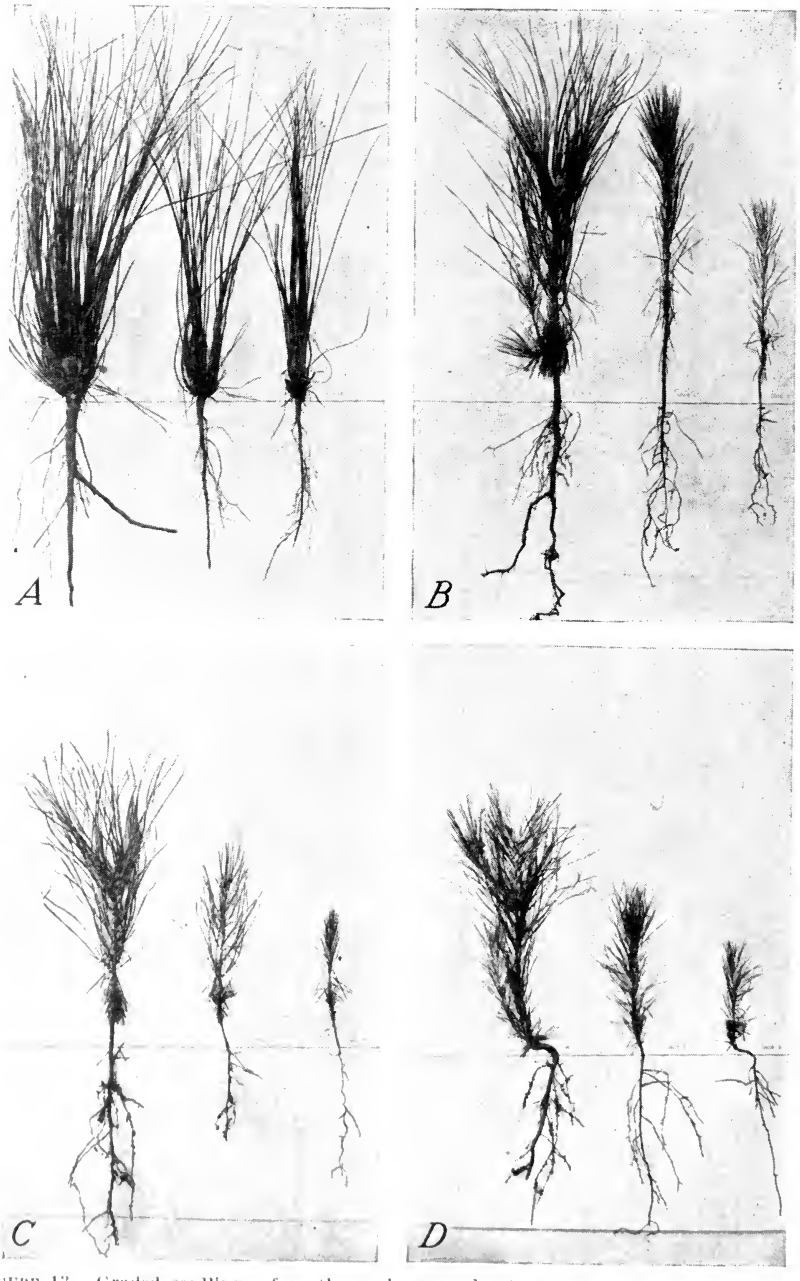

FIGURE 13.—Graded seedlings of southern pines, grades 1, 2, and 3 (from left to right): *A*, Longleaf; *B*, slash; *C*, loblolly; *D*, shortleaf.

The most clear-cut results obtained by the Southern Forest Experiment Station in its planting experiments have been those bearing on the use of various grades of planting stock. These results have been abundantly confirmed by general experience practically throughout the southern pine region.

In the station's principal grading experiments, conducted at Bogalusa, La., slash pine seedlings of grades 1, 2, and 3 were planted alternately by rows. Altogether, 200 seedlings of each grade were planted. A similar experimental plantation of loblolly pine was established at the same time. The following year the plantings of both slash and loblolly were duplicated on an area nearby. In analyzing the figures, all trees that had been subjected to injury not influenced by grade were omitted; consequently the conclusions are based not on the total 2,400 trees planted but on 2,136.

The results were practically the same with both species and in both series of plantations, the chief difference being that the benefits of grading showed more strikingly on the poorer site. After 1 year in the field, in 6 cases out of 8 a grade 1 or grade 2 group showed a higher percentage of survival than the corresponding group of next lower grade, with a maximum difference of 10.9 percent. After 5 years in the field, in 7 cases out of 8 a grade 1 or grade 2 group survived better than the corresponding group of next lower grade, with a maximum difference of 16 percent. The maximum difference in survival between grade 1 and grade 3 seedlings after 5 years in the field was 21.7 percent.

In the one instance in which survival (of loblolly pine) for a given grade was less than that for the next lower grade both after 1 year and after 5 years in the field, the higher-grade stock was discovered to be infested with scale insects.

In every instance, undamaged seedlings of grade 1 or grade 2 were taller than undamaged seedlings of the next lower grade. At the end of the second year in the field grade 1 seedlings were 33 to 112 percent taller than grade 3 seedlings, the difference varying with species and height, and at the end of the fifth year they were still 25 to 71 percent taller. The height relationship of the different grades of slash pine and of loblolly pine are shown in figures 14 and 15, for both uninjured stock and stock injured by rabbits the first year in the field. Figure 16 shows the appearance of the different grades of stock after 5 years in the field.

The experiments showed that high-grade stock, particularly in the case of slash pine, was less subject to rabbit damage during the first year in the field than that of lower grade. (Injury by rabbits during the second year was usually confined to nipping off side branches, and had little effect on vigor as shown by height growth.) In 6 cases out of 8 the higher the grade the lower the percentage of stock damaged by rabbits, with a maximum difference between consecutive grades of 14.4 percent. One group of grade 3 (slash pine) stock suffered 37.8 percent more damage from rabbits than the corresponding group of grade 1 stock.

The influence of rabbit injury on height growth of stock of different grades is shown in figures 14 and 15. Details of survival and rabbit damage, by grade, are given in table 19.

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Studies of longleaf pine in experimental plantations and in commercial plantations indicated that high-grade seedlings not only suffered less from brown spot and silting but also began height growth at an earlier age than did low-grade seedlings. Indeed, grade 1 stock

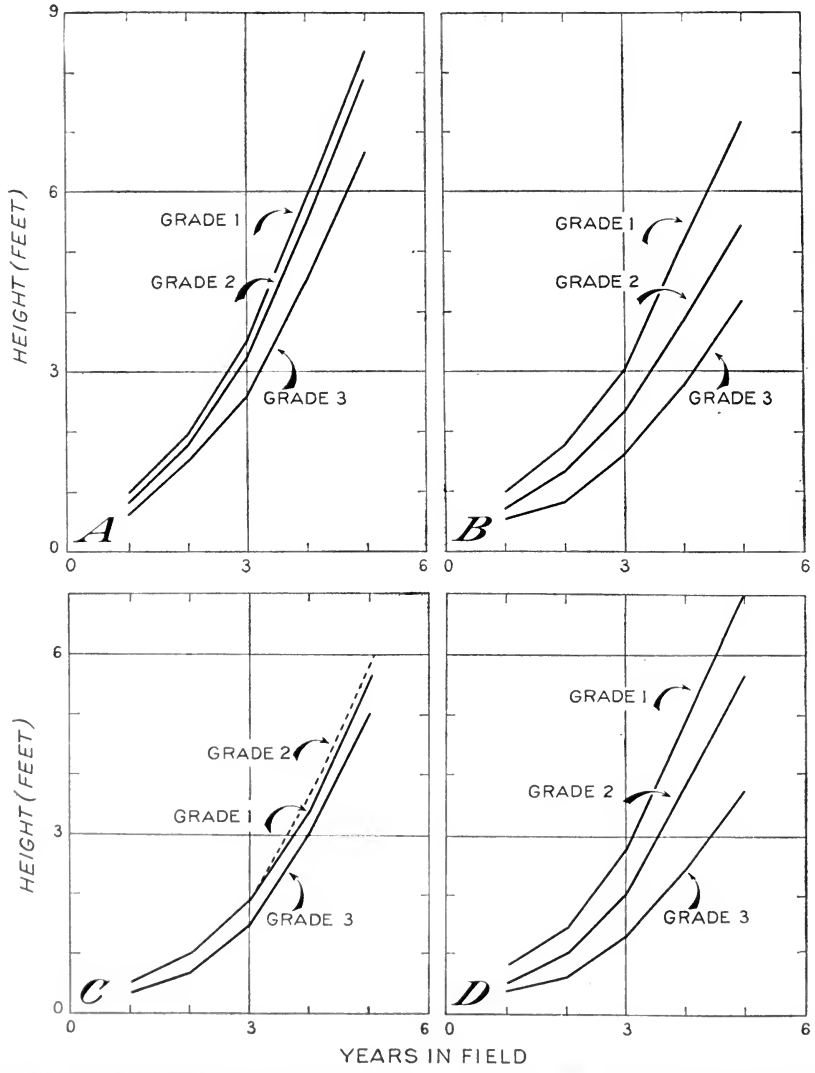

FIGURE 14.—Relative growth made by two successive plantings of slash pine stock (grades 1, 2, and 3) during the first 5 years in the field; *A* and *C* planted 1924–25 and *B* and *D* 1925–26. Effect, on growth, of rabbit injury at the beginning of the first growing season is shown in *C* and *D*; *A* and *B* show growth of uninjured stock.

that had been planted properly grew far faster than the best natural stands.

In 1928–29 the Great Southern Lumber Co. established an experimental plantation near Bogalusa, La., to test in detail the difference in survival and growth between grade 1 and grade 3 longleaf pine stock. Two plots of approximately one-fourth acre each were laid

out approximately 200 yards apart, on adjacent low ridges on a typical cut-over longleaf pine tract, and were planted with stock of the two grades, respectively. The growing conditions were nearly identical; if anything, the soil was slightly better on the plot planted with grade 3 stock. Four years later, the apparent survival on the grade 1 plot was 82 percent and that on the grade 3 plot was only 49 percent. It is possible that some of the surviving grade 3 seedlings were overlooked in the grass, because of their small size. On the grade 1 plot 22 trees out of 200 were 6 inches tall or taller, and the

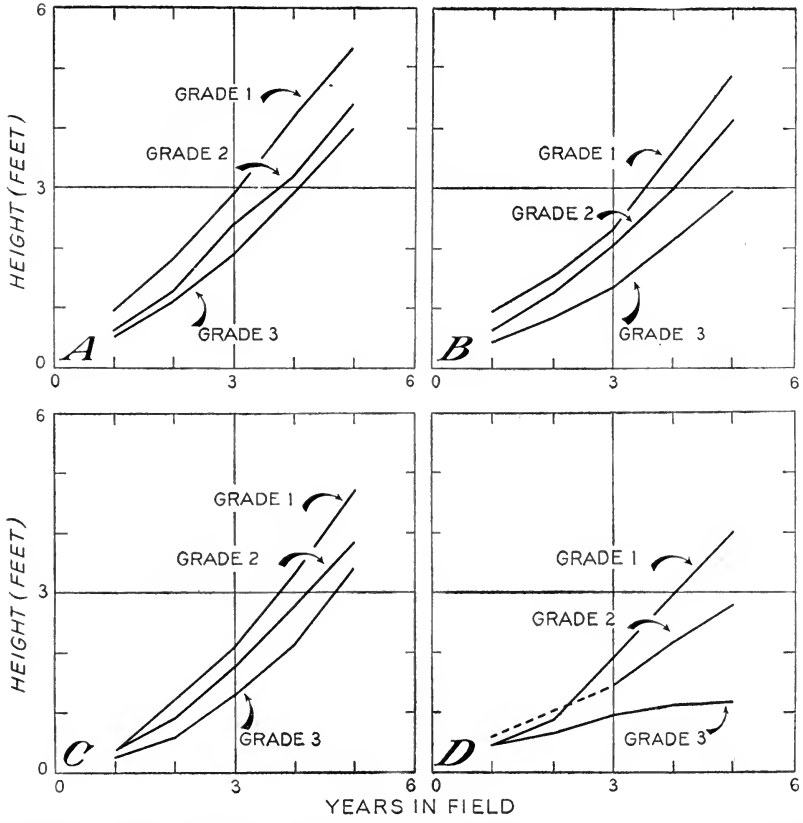

FIGURE 15.—Relative growth made by two successive plantings of loblolly pine stock (grades 1, 2, and 3) during the first 5 years in the field; *A* and *C* planted 1924–25 and *B* and *D* 1925–26. Effect on growth of rabbit injury at the beginning of the first growing season is shown in *C* and *D*; *A* and *B* show growth of uninjured stock.

tallest was 46 inches. On the grade 3 plot only 3 trees out of 112 had reached a height of 6 inches, and none exceeded that height. The exact distribution of seedlings by height classes is shown in figure 17, in terms of percentages of the total number of seedlings observed that attained specified minimum heights.

By the system outlined in the foregoing, the percentage of grade 1 stock can be determined without lifting the seedlings. This percentage, in connection with density determinations and other observations, is an index to the success of various seed-bed treatments.

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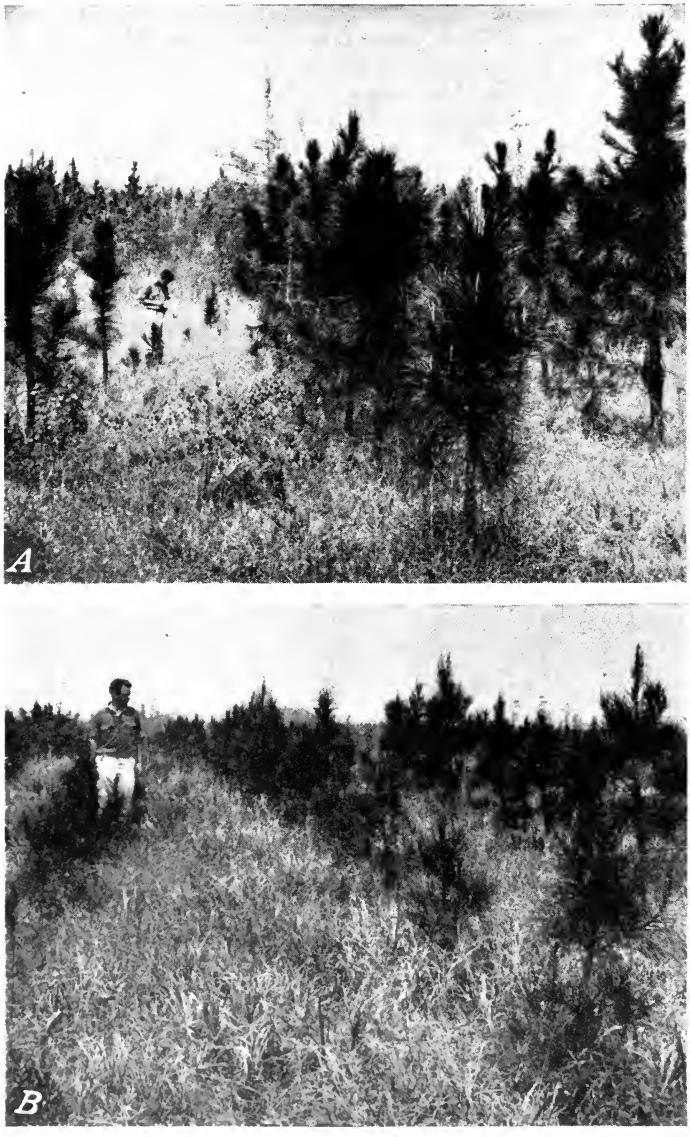

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FIGURE 16.—*A*, Slash pine stock of three different grades after 5 years in the field. Grade 1 stock is on the right, grade 2 in the middle, and grade 3, including the small seedlings in front of and behind the man, on the left. *B*, Loblolly pine stock of three different grades after 5 years in the field, on a site poor for the species. Grade 1 stock is on the extreme right, grade 2 in the right foreground and center, and grade 3 at the extreme left by the man.

TABLE 19.—*Percentages of stock of different grades injured by rabbits, and percentages surviving, in slash pine and loblolly pine plantations*[1]

Species, date of planting, and character of site	Grade	Seedlings planted[2]	2-year-old seedlings injured		Stock surviving at end of—				
			In first year only[3]	Total	1 year	2 years	3 years	4 years	5 years
		Number	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Slash pine planted 1924–25, better site	1	202	16.8	22.2	93.1	91.6	90.6	90.1	89.6
	2	196	21.6	31.0	90.3	87.2	86.7	86.2	85.7
	3	191	21.8	27.3	88.5	86.4	85.9	84.3	83.8
Slash pine planted 1925–26, poorer site	1	130	3.3	30.6	93.8	93.1	93.1	90.0	90.0
	2	129	16.7	53.7	84.5	83.7	81.4	79.8	78.3
	3	123	41.1	57.9	82.1	77.2	70.7	69.9	68.3
Loblolly pine planted 1924–25, better site	1	194	10.7	11.8	96.9	96.4	95.4	95.4	95.4
	2	191	17.6	19.4	88.5	86.4	86.4	86.4	86.4
	3	188	11.8	13.6	91.0	89.9	88.3	86.2	85.6
Loblolly pine planted 1925–26, poorer site	[4]1	197	1.3	6.7	76.6	75.6	75.6	75.6	75.6
	2	199	1.6	5.5	93.0	91.5	91.0	91.0	90.5
	3	196	.6	3.9	82.1	78.6	77.6	76.5	74.5

[1] Table based on data for 2,136 seedlings planted at Bogalusa, La.
[2] Exclusive of a few trees rejected because of definitely determined injury not traceable to grade.
[3] Injury by rabbits the first year ordinarily involves cutting off the entire top of the seedling, and is more serious than later injury, which frequently involves only the clipping of side branches.
[4] The mortality in this grade was increased by action of scale insects, but the records were not sufficiently detailed to permit rejection of individual trees as described in footnote 2.

The most conspicuous differences between grades result from differences in seed-bed environment, in age, or in both. Low-grade seedlings result more often from overcrowding than from any other cause. Poor soil quality, abundance of weeds, and insufficiency of water are other important factors.

Trees from seeds germinating late in the season usually fall in grade 3, because of their disadvantage in competing for moisture and light. Insect injuries during spring or summer are another frequent cause of low grade. Another is undue delay in sowing the nursery as a whole.

Because grade is so largely a matter of seed-bed environment and of age, grade 2 stock may frequently be planted with perfect safety on favorable sites. On areas where site is more adverse, including those where there is much competition from other plants, grade 1 stock should be used whenever possible. Grade 3 stock, as here defined, cannot compete with native vegetation or stand up under the extremes of temperature or the fluctuations in moisture supply common throughout the region.

Seedlings infected with fungus or infested by insects at the end of the growing season, and seedlings injured in lifting, should be culled.

LIFTING

To date, most nursery stock grown in the South has been lifted by hand.[14] The usual practice, which produces satisfactory results so far as growth and survival are concerned, is to lift the stock with long-handled square spades, the edges of which are kept sharpened with files. Use of the highest-grade spades obtainable saves much

[14] The Forest Service and other agencies have developed for use in the North and West several types of mechanical seedling lifters (drawn by horses, tractors, or winches) that loosen the soil and prune the roots in a single trip down a standard seed bed (*23, 30*). The Forest Service is now adapting this equipment for use in the southern pine region.

time and cost in filing the edges, more than making up for the slight extra initial cost.

A trench about 12 inches deep is dug at the end of the bed. A spade is driven into the soil horizontally at a depth of 8 or 10 inches, cutting the roots fairly cleanly. The spadeful of soil containing the seedlings is then lifted out to the ground at the side of the bed. It is set down rather hard, to cause crumbling. One man does the digging in each bed. Two to four men follow each lifter down the beds, freeing the seedlings from the soil, culling the grade 3 seedlings and the injured seedlings of higher grade, and laying the good seedlings neatly together in readiness for the packers.

It is common practice to protect the piles of good seedlings by covering the roots with earth. Wet sacks could profitably be substituted.

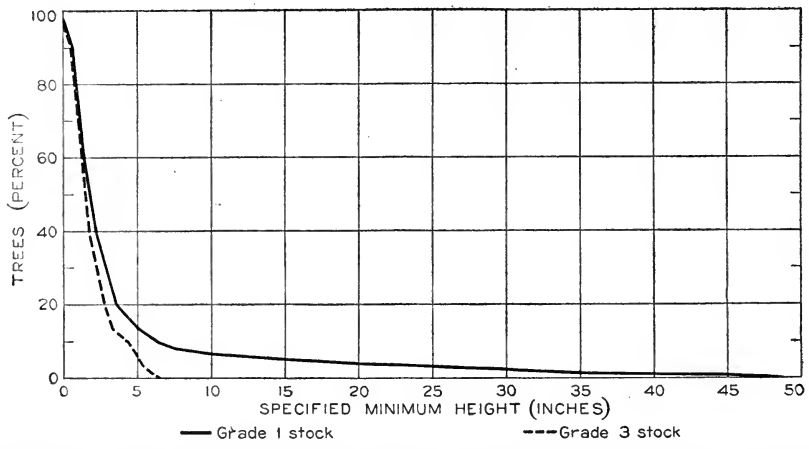

FIGURE 17.—Relative height distribution of grade 1 and grade 3 longleaf pine stock, after 4 years in the field, in experimental plantation established by the Great Southern Lumber Co. (basis, measurement of 200 grade 1 trees and 112 grade 3 trees).

The presence of many weeds in the nursery adds considerably to the cost of lifting, in extreme cases nearly doubling it. Bright, sunny weather somewhat increases the cost of lifting because it increases the frequency with which the sorters must stop to cover the roots.

In transporting the seedlings to the packers much waste of motion can be prevented by using two (or more) wheelbarrows, leaving one to be emptied by the packers while another is being filled at the beds. To protect the seedlings, wet moss should be used in the bottom of the wheelbarrow and wet burlap sacks over the top.

Counting the seedlings is necessary only if they are to be sold. If a count is required, usually it is made by the packers. Quantities of stock can be computed approximately by sampling representative beds before the stock is lifted. These computations can be checked by counting the seedlings in sample bundles and the bundles in sample crates, and further checked by totaling the area planted and computing an average of the number of seedlings planted per acre.

PACKING

In order that seedling roots may be kept moist at all times, the seedlings must be packed in some moisture-retentive material from the time they are lifted until they are heeled in or planted. This material should be the lightest and cheapest that will remain effective through the necessary handling.

One of the packing methods most common in the South employs sphagnum moss and light cardboard or waterproof paper. From 50 to 100 seedlings are wrapped in one bundle; 50 longleaf seedlings, or 75 grade 1 slash pine or loblolly pine seedlings, are about all that can be grasped and rolled efficiently. Another efficient method of handling seedlings is to bale them in burlap. Another is to pack them in the body of a truck lined with wet sacks and cover them with wet sacks and heavy canvas for direct transportation to the heeling-in bed. Small lots of seedlings may sometimes be transported economically by truck in washtubs full of water.

In wrapping seedlings in bundles, use is made of sections of light cardboard (known as "container lining") or waterproof paper, 16 by 16 inches to 18 by 24 inches. The wrapper should be long enough to project about 5 inches beyond the pruned ends of the roots and still extend to the tips of the stems of seedlings other than longleaf pine, or nearly to the ends of the needles of longleaf seedlings. Having laid such a wrapper on the bench or ground before him, the packer places on it a layer of sphagnum moss one-half inch thick and large enough to keep the paper from coming in contact with any of the roots or the lowest 2 inches of the stems. Next he lays a handful of seedlings on top of the moss, with their root collars all together. He then claps another ½-inch layer of moss over the mass of roots and begins to roll the bundle away from him, squeezing the roots tightly. After completing one turn of the wrapper around the roots he turns up the length of wrapper extending beyond them. The paper then forms a tube, closed at one end, that surrounds the seedlings and holds the wet moss in contact with them. When the wrapper has been rolled completely around the bundle, it is tied in place with light cord.

Longleaf pine seedlings are harder to pack than seedlings of the three other species, because of their lack of stems.

Shingletoes, the long stringy shavings left from sawing shingles, make very nearly as good a packing material as sphagnum moss. The light cardboard used for packing seedlings must be soaked in water to make wrapping easier. This is usually done in pits dug in the ground. Because the cardboard is weakened by soaking, it is better to use the grade in which a thick layer of board made from waste-paper pulp is backed by a thinner layer made from fresh kraft-paper pulp. The string used to tie the bundles should be soft so as not to cut the wrappers, and not so fine as to cut the packers' fingers. Tying the string with a slip knot instead of a hard knot saves the necessity of cutting or breaking it in the field.

Any desired number of bundles may be baled in burlap, with a reinforcement of cleats, for shipment by truck or rail, or bundles may be packed on end in large crates for trucking. Seedlings wrapped in bundles as just described ordinarily remain moist for from 3 days to a week even in open crates, if the crates are not exposed

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to full sunlight. In bales, they may remain moist even longer. Seedlings in open crates can sometimes be kept in good condition for as long as 2 weeks, if the weather remains cool and if additional water is poured into the upper ends of the bundles.

Seedlings either in bundles or in loose masses can be packed safely and efficiently in a very light container by using the Olson baler, developed by the Forest Service. This is a box 18 inches wide, 15 inches deep, and long enough that two bundles of the tallest stock can be laid end to end in it with their roots overlapping only slightly. It has no top, and the front side is hinged so that it can be dropped to permit removal of the bale. The apparatus is raised to a convenient working height. The packer makes a loop at one end of each of two baling wires and lays the wires in the box, bending them to conform to its shape and hooking the ends over the front and back, with the loops at the front. He then lays two cleats in the box, and over them a layer of burlap and a layer of waterproof paper. Both burlap and paper are long enough to line the front, bottom, and back of the box and overlap on top. A layer of wet sphagnum moss 1 or 2 inches thick is placed in the bottom of the box, covering it completely. A layer of seedlings is placed on the sphagnum, with the tops toward each end of the box and the roots slightly overlapping in the middle. This layer is perhaps 4 inches deep. A ½-inch layer of sphagnum is placed over the roots, and sphagnum is tucked in between the seedlings and the front and back of the box. Successive layers of seedlings and moss are added until the box is full, the last layer of sphagnum being 2 inches thick. The paper is then folded over the moss, and the two ends of the burlap are brought together and rolled around a stick, 2 inches square, fitting into the box lengthwise. When the burlap has been rolled as tightly as is possible by hand, it is rolled more tightly by using a rolling handle (a large wooden socket wrench) on this square stick. Holding the rolling handle in place, the packer then slips the pointed ends of the wires through the corresponding loops and back through holes in a pipe fastened to the far side of the box. A few turns on a crank handle at one end of this pipe pull the baling wire as tight as its strength will allow. The wire by this time is so sharply bent where it passes through the loop that it can be cut off. After being given a turn around itself, it is tucked into the burlap.

The material used in packing seedlings with the Olson baler costs less than $0.15 per bale. Exclusive of the wet moss, it represents less than 5 percent of the total weight of the bale (*23*).

TRANSPORTATION

The need of getting seedlings to the planting site before they dry out usually requires that they be shipped by truck or by express; freight is too slow. As packed for shipment, southern pine seedlings weigh from 20 to 50 pounds per 1,000. Seedlings wrapped in paper in bundles of 50 to 100 run 6,000 to 10,000 to a crate measuring 2½ by 3 by 4 feet, the lower figure being for longleaf pine and the higher for small slash pine seedlings or for loblolly pine seedlings of average size. Three such crates are about as large a load as a 1½-ton truck can take onto an ordinary planting site.

HEELING-IN

If seedlings must be held before packing at the nursery, or held at the planting site, they should be heeled in. This process should be attended to with the utmost care. The best heeling-in ground is moist, easily worked soil exposed neither to full sunlight nor to excessive cold. If natural shelter is lacking some sort of brush, burlap, or canvas shelter should be provided. The seedlings are placed against the side of a shallow trench, their tops projecting above the ground slightly less than when they stood in the seed bed. They should be in a layer not more than 3 or 4 inches thick. The side of the trench against which the seedlings are placed may be nearly vertical or may slope as much as 45°. A slope simplifies the packing of a 3- or 4-inch layer of moist earth against the roots. A thicker layer of earth should be used if only one layer of seedlings is to be heeled in. Heeling-in beds should be kept moderately moist. Extreme wetness, however, makes it difficult to get the seedlings out of the trench again, and if water is allowed to stand in the trenches for any length of time it may cause injury to the plants.

REGULATIONS GOVERNING SHIPPING

Practically all States regulate in some way the shipment of nursery stock from other States, and a few States regulate shipment across quarantine lines within their own boundaries. In addition, Federal quarantines are established from time to time. No attempt should be made to ship stock by common carrier or across State lines by truck without obtaining from the State plant board or the State nursery inspector or other designated official information concerning the latest regulations and the mode of obtaining any certificate required. The present titles and addresses of such officials for the various Southern States are given in the appendix (p. 114).

Ordinarily no special quarantines affect southern pine nursery stock. Even in the absence of such quarantines, however, no agency should ever ship infected or infested nursery stock anywhere other than to its own plantations, and stock harboring insects or fungi capable of continuing their activities in plantations should be destroyed.

Express companies make a few simple requirements concerning containers for railroad shipments. Crated or baled material must be in such condition that it cannot injure other merchandise being shipped, and must be put up substantially enough to withstand ordinary handling. Material such as nursery stock should, of course, be marked as "perishable." Substantial crates or well-packed burlap bales are entirely satisfactory if they are not wet on the outside and if no points of wire project from them such as might tear the covering of other shipments. Small bales of seedlings wrapped in waterproof paper or heavy cardboard are ordinarily acceptable if moisture does not soak through and soften the wrappers. If the State to which seedlings are consigned requires nursery-inspection tags, shipping agencies refuse to accept the seedlings until the appropriate tags have been attached.

PLANTING TOOLS AND THEIR USE

TOOLS

The tool recommended for planting southern pine seedlings is the planting bar, known locally as the "digger" or "dibble." This tool is peculiarly adapted to southern soils and southern pine nursery stock. As originally developed, it has a wedge-shaped steel blade 3½ inches wide, 10 inches long, and three-fourths inch thick at the top, with a square or slightly rounded cutting edge. This is welded at the top to a straight ¾-inch iron rod ending in a D handle. A

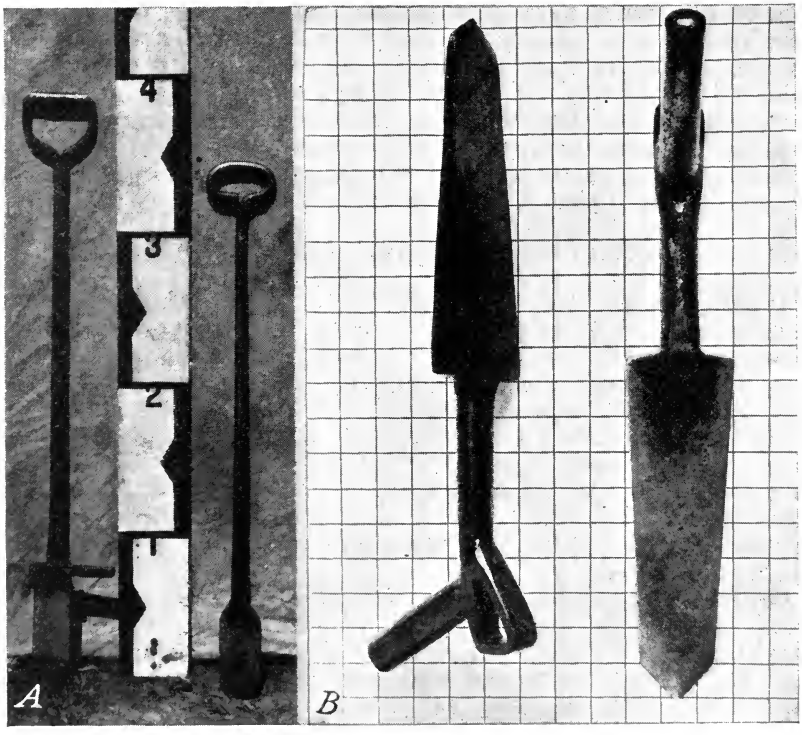

FIGURE 18.—*A*, Two types of the iron planting bar used in planting southern pine. That on the left has a detachable step. The scale in the center indicates feet. *B*, Choctawhatchee planting tool, designed for use by a man working alone on light soils, especially on brushy sites (background ruled in inches).

recent development is the addition of a 3- to 4-inch step welded or bolted to the top of the blade on one side, which enables the planter to drive the bar into the ground with his foot. The planting bar is shown with and without this modification in figure 18, *A*.

Planting bars can be made by any competent blacksmith at a cost of $1 to $2 each, or purchased from commercial concerns. The blade should be of good tool steel, and the joint between blade and handle should be strongly welded. The size of the grip should be such that a glove can be worn and there will be no danger of rubbing the knuckles across the lower part. In its most generally suitable form the tool is 45 inches long over all and weighs 10 pounds. A planting bar 47 or 48 inches long is very tiring to the arm of any

man less than 6 feet tall, except on very light, sandy soil, and one as short as 42 inches tires the back of a tall man. A weight of 12 pounds is excessive, but a weight much below 10 pounds is inadequate for most successful use except on unusually light soils.

A tool requiring only one hand and making a slit has been tried recently with encouraging results on light and moderately light soils, particularly where brush interfered with the handle and roots with the blade of the larger planting bar (*13*). It seems ineffective, however, on very hard or heavy soils. This tool is shown in figure 18, *B*.

The mattock, used commonly for forest planting in other regions, is not extensively used for this purpose in the southern pine region. It has been used to some extent on the piedmont soils and some of the Coastal Plain soils in the northern part of the region, and on the relatively stony soils in the Ozark Mountains in Arkansas. On the Ozark National Forest, Ark., however, the planting bar was tried by L. S. Gross in the spring of 1933 with success on all but the stoniest ground. On cut-over longleaf pine lands, which present the major planting problem in the South, the heaviness of the subsoil and its proximity to the surface prevent most efficient use of the mattock and give the planting bar a great advantage in speed. Longleaf pine planted by the mattock-hole method is especially subject to damage from silting.

Seedlings have been planted successfully with a great variety of makeshift home-made implements, but the use of such tools on large-scale planting operations results in unduly high costs.

METHOD OF PLANTING

Planters using the planting bar work in pairs. The man with the bar drives the blade straight down into the ground, making a slit at right angles to the direction in which he is facing. When he has driven the blade in to its full length, he moves the handle back and forth, with both hands, just enough to free the blade from the soil. It is bad practice to move the handle through an arc of 25° or more. To do so opens a hole somewhat like an hourglass in vertical section, which is extremely difficult to close properly about the roots. Skillful planters make a slit very little wider than the blade of the tool itself. Frequently a second stroke is necessary to make the slit deep enough.

As soon as the blade is withdrawn the second man slips a seedling into the slit, shaking it to spread the roots as naturally as possible and holding it upright at the desired depth (discussed in the fourth paragraph following). Care must be taken not to double up the root system or leave any of the roots projecting above the surface of the ground.

When the tree has been brought into position, the bar is driven forward into the ground at an angle of about 30° with the vertical, just far enough behind the seedling to insure that the edge of the blade will not strike the roots. This distance differs somewhat according to soil, but is usually about 4 or 5 inches. As the man with the bar completes the stroke he bears down on the handle. This movement, forcing the lower portion of the blade forward, effectively closes the lower part of the slit containing the tree. If the

movement is correctly executed, the man holding the seedling can feel the soil plucking at the roots. Next a slight upward motion of the handle frees the blade from the soil and to some extent closes the top of the slit. The man with the bar, as he follows the man with the trees to the next planting place, completes the closing of the slit by driving his heel against the loose earth.

Under ordinary conditions two men working together in the manner described can plant from 1,600 to 2,200 trees in an 8-hour day, or somewhat better than 3 trees a minute.

In using the modified planting bar all the motions are the same as those just described, except that the man with the bar, having brought it into place in an upright position by thrusting his arm well forward, completes his last stride toward the planting spot by bringing his foot down on the step at the top of the blade. He thus makes his weight and his leg muscles do much of the work done by arm and shoulder muscles when the stepless planting bar is used. The bar with the step is the less fatiguing of the two, except on very hard or heavy soils. In such soils impact, not pressure, is needed to make a slit, and it is necessary to drive the blade in by sheer strength of arm and shoulder.

The proper depth for planting southern pine seedlings is the depth at which they grew in the nursery bed, except in the case of longleaf pine. The difference in color between root bark and stem bark reliably indicates this depth. Longleaf pine seedlings make no height growth until they have been in the field at least one full season. In plowed furrows, on light sandy soil, or on sloping sites recently burned over, they are thus very likely to be covered by rain-washed soil unless they are set one-half to three-quarters inch higher in the field than they were in the nursery. Any man planting longleaf seedlings should be directed to grasp each seedling by the taproot, with the index and middle fingers, just at the root collar, so that the roots hang down below the fingers and the top lies across the palm and the wrist. When he inserts the roots in the slit made with the planting bar, the man with the seedling rests the knuckles of his first and second fingers on the surface of the ground, and the thickness of his fingers automatically "sets up" the seedling at just about the desired height. Even if soil wash fails to build up the level of the soil to the normal root collar of the seedling, the thick bark characteristic of longleaf pine seedling roots enables the trees to survive.

CONTAINERS FOR STOCK

The usual container for carrying planting stock is a pail. When pails are used, most planters prefer to keep the seedlings moist by means of sphagnum moss only, rather than be bothered by water in the bottoms of the pails. Care is necessary to keep the moss around the roots at all times.

Because pails are heavy and expensive and are likely to be stolen, one company has used two-compartment canvas planting bags in which, if need be, two species can be carried at one time, and has found them highly satisfactory. The trouble with both pails and bags is that in these receptacles stock as large as southern pine seedlings must be carried in an upright position. In pulling one upright seedling free from others, there is danger of stripping off part

of the root system. Ordinary market baskets are preferable because their length permits carrying the seedlings in a horizontal position. Seedlings so carried are not only easier to detach one at a time but easier to keep covered than seedlings carried in a pail or bag. The baskets are light, and their rigid handles make them easy to manage in tall grass and brush. They are generally inexpensive, especially when purchased in large quantities. The Forest Service uses watertight galvanized-iron trays similar to a market basket in size and shape. Although more durable than the baskets, these have a disadvantage in their greater weight.

ORGANIZATION OF SQUAD

The number of men needed for a southern pine planting operation is governed principally by the need of completing a season's planting program between the beginning of dormancy (or the occurrence of the first winter rains) and the beginning of the new growing season.

In planting with the planting bar, ordinarily 12 or 15 two-man crews are all one foreman should undertake to supervise. If the planters are experienced and highly reliable larger numbers may be supervised by one foreman, or individual planters may act as foremen of small groups and one boss or straw boss can supervise a considerable number of such groups. A boss can handle upward of 50 two-man crews; a good boss assisted by one or more straw bosses may be able to supervise 250 crews working in clear level country. Small squads are ordinarily preferable.

The boss is responsible for decisions as to laying out the job, for arrangements regarding seedling supplies, and for prompt movement from one planting area or portion of planting area to the next. He is responsible also for setting the standard of work. The foremen are responsible for spacing and alinement, proper setting of the trees, and promptness and efficiency in the work. More responsibility falls upon the foreman where planting is done without site preparation, because he must then set flags on one or both flanks of his squad to guide the end crews, and must see that the other crews remain at the proper spacing. He must also see that the proper spacing is maintained in individual rows.

A planter can satisfactorily carry 200 longleaf pine seedlings or slash pine seedlings, and as many as 500 small loblolly or shortleaf pine seedlings. To load planters' pails or baskets with quantities of stock much larger than these results in unnecessary fatigue and often leads to failure to keep the roots moist. On the basis that 200 trees spaced 6 feet apart will plant a row nearly one-fourth mile long, it is relatively simple to lay out an area to be planted so that by the time the planters have emptied their baskets they will have worked their way approximately back to the heeling-in ground or delivery point for seedlings or will have reached some place to which extra supplies of seedlings can be delivered.

A common arrangement is to load planting-stock supplies, and also supplies of drinking water, on a light horse- or mule-drawn cart and have this driven to meet the crews at suitable intervals. Frequently it is possible to have one cart supply two crews working from the same heeling-in ground. The hours at which addi-

tional supplies are needed by two crews working together can be staggered simply by starting one crew at the beginning of the day with only half the usual supply of stock.

Good alinement can be maintained by starting out with the more rapid and skillful planters at the left-hand end of the line and having the first pair guide on a series of two or more flags set in a straight line. The foreman must go ahead and set additional flags from time to time if the strip to be planted is extremely long. The flags must be set in such a position and close enough together so that the next two ahead are always in sight simultaneously. The remaining crews string off to the right of the guide crew at the chosen planting interval and the foreman checks their spacing now and then by pacing or by measuring with a pole. Better alinement is obtained if two rows of flags are used and the faster crews are assigned to the two ends of the line. In that case the right-hand row of flags is left in place to serve as a guide on the return trip. White or white-and-red flags on rods about 10 feet high are usually satisfactory.

RATES AND COSTS

On typical cut-over longleaf pine sites, two men working with the planting bar can ordinarily plant 1,600 or more trees per 8-hour day. A decrease in number of trees planted per day, and a corresponding increase in cost, results from any of these conditions: Uncomfortably cold weather, rain, water standing on site, sticky clay soil, clay subsoil within 6 inches of the surface, and heavy brush. Cost is increased also by using stock less than 10 inches or more than 18 inches tall or stock having very bushy root systems. Grade 3 stock of a given species is estimated to cost 10 to 20 percent more to plant than grade 1 stock. Slash pine seedlings of good quality are usually the easiest to plant correctly; longleaf pine seedlings are likely to be the second easiest. Planting in the rough does not seem to be appreciably slower than planting in furrows.

Large fluctuations in the total cost of planting are usually the result of fluctuations in the cost of nursery stock, and an upward tendency in total cost is almost invariably linked with high nursery costs.

As has been mentioned in connection with spacing, reduction of number of trees planted per acre reduces the per acre cost of stock and, in lower proportion, that of labor.

PLANTATION

INJURIES AND PROTECTION

No plantation should be established without natural or artificial firebreaks and an organized fire-control system. (This does not mean that artificial reforestation of a given area should be postponed until the fire-control system serving the area has been perfected in every detail.)

The susceptibility of southern pine plantations to fire varies greatly with species and age, and also according to vegetative state (active or dormant), weather at time of burning, and quantity of fuel present. Slash pine is more resistant than loblolly pine of the same age

and height. In one instance, at Bogalusa, La., a severe March fire in adjoining 7-year-old plantations of slash and loblolly pine killed 1 percent of the slash and 53 percent of the loblolly. Shortleaf pine is killed back by fire as easily as loblolly pine, but plantations of shortleaf are seldom killed outright by burning because the young trees of this species sprout from the root collar. Longleaf pine is the most fire resistant of the four species. Young plantations of longleaf pine, especially during the period when they are well established but have not yet begun height growth, sometimes endure hot fires in fall, winter, or even early spring without suffering serious losses; a 9-month-old plantation at Elizabeth, La., burned in September, two 2-year-old plantations on the Choctawhatchee National Forest, Fla., burned in December, and a 2-year-old plantation at Bogalusa, La., severely burned in March, suffered mortalities of only 10, 14, 5, and 5 percent, respectively.

Slash pine stands 5 years old or older, and longleaf pine stands that have begun height growth, frequently undergo partial defoliation by fire without suffering severe mortality, although they usually suffer a perceptible reduction in growth for a year or two. The burned portion of the 7-year-old slash pine plantation at Bogalusa, previously mentioned, increased in height an average of 2.2 feet the year after the fire; the adjoining unburned portion increased in height an average of 3.5 feet during the same period. The burned portion of a 6-year-old slash plantation at Bogalusa suffered 7 percent mortality as a result of a March fire and in the following year increased in height only 1.5 feet, as against an increase of 3.1 feet on the adjoining unburned portion. The burned portion of a 4-year-old slash plantation in Harrison County, Miss., suffered 8 percent mortality as a result of a winter fire, and in the following year made approximately 25 percent less height growth than the unburned portion. For longleaf pine plantations the diminution in height growth resulting from fire appears to be less serious than for slash plantations, although precise data on the subject are not available.

Planted longleaf pines that have begun height growth, and planted pines of the three other species at all stages of growth, increase rapidly in fire resistance with increasing age. Fire losses in three 2-year-old slash pine plantations, two at Bogalusa, La., and one on the Choctawhatchee National Forest, Fla., were 86, 100, and 99 percent, respectively, in contrast with 8, 7, and 1 percent, respectively, in the 4-, 6-, and 7-year-old slash plantations described in the foregoing. In planted loblolly pine at Bogalusa, 3 fires occurring when the trees had been from 1 to 4 years in the field caused 100 percent mortality, whereas the fire in the 7-year-old loblolly plantation already mentioned caused a mortality of only 53 percent.

Winter fires ordinarily injure the trees far less severely than fires during the growing season.

The ability of longleaf pine to survive fire and of shortleaf pine to sprout after being killed back by fire is a strong argument in favor of mixing these species with less fire-resistant species on suitable sites in localities where fire danger is high.

Longleaf pine suffers seriously from damage by hogs, particularly razorbacks and crosses between razorbacks and some of the domestic breeds. Purebred hogs of the best strains appear to do much less

damage. The hogs kill smaller seedlings and occasionally injure or kill trees up to 10 feet high by eating the thick bark on the taproots. Counts of longleaf pine seedlings eaten by hogs show clearly that one hog could destroy in a single day an entire acre of longleaf pine spaced 6 by 8 feet. Any planting program in which dependence is placed on longleaf pine must therefore include careful provision for fencing out hogs or for keeping them out of the plantations by agreement with the owners and by rigorous herding and hunting. Hogs destroy slash pine, also, but less often.

Sheep and goats are capable of doing much damage to slash, loblolly, and shortleaf pine plantations. No records are available of their injuring seriously longleaf pine seedlings that had not yet begun height growth, but they check the height growth of taller longleaf pine seedlings, sometimes for many years, by biting off the terminal buds. They should not be permitted to graze on planted areas.

Horses and cattle do no substantial damage to pine plantations except on limited areas where they concentrate because of shade or particularly good feed. A patch of carpet grass in a plantation in which most of the native vegetation consists of wire grass or broomsedge may cause such concentration. The damage is usually limited to trampling very young seedlings and to breaking older seedlings (in smaller numbers) by rubbing against them in an effort to get rid of insects.

Cottontail rabbits (*Sylvilagus* sp.) frequently do serious injury to plantations of slash, loblolly, and shortleaf pine. They bite off large numbers of freshly planted seedlings and occasionally bite off the smaller and more tender sprouts of seedlings beginning their second year in the field. In ordinary seasons many of the injured seedlings survive, but the mortality resulting from rabbit injury is too great to be ignored, and the height growth of the survivors is generally slower than that of uninjured seedlings. Why the rabbits bite off the seedlings is not known; the tops show little or no signs of parts having been eaten and are usually left lying beside the seedling stumps, which may be anywhere from one-fourth inch to 5 or 6 inches high. Figure 19 gives a comparison between the heights of uninjured high-grade seedlings of slash, loblolly, and shortleaf pine, and high-grade seedlings of those species set out at the same time but injured by rabbits. This type of damage can be reduced by hunting rabbits assiduously the winter before planting and by using high-grade stock or by planting only longleaf pine, which is rarely or never injured by rabbits. (Differences in rabbit damage corresponding with differences in grade of planting stock are discussed on p. 81.)

Some damage to seedlings by rats has been reported, and seedling roots are occasionally injured by "salamanders" (*Geomys* sp.), particularly on sandy soil; but damage of this sort is relatively unimportant through the southern pine region as a whole.

The Nantucket tip moth, previously mentioned as a nursery pest, is the most conspicuous example of insects injurious to young pine stands. This moth is a shoot-boring insect practically impossible to reach with poison except in the egg stage. It does serious damage to loblolly and shortleaf pines; in some instances it has caused aban-

donment of these pines for purposes of artificial reforestation. It attacks slash pine, but does relatively little damage to it and may not be able to reach maturity upon this species as easily as upon the two just mentioned. Only two records of its appearance on longleaf

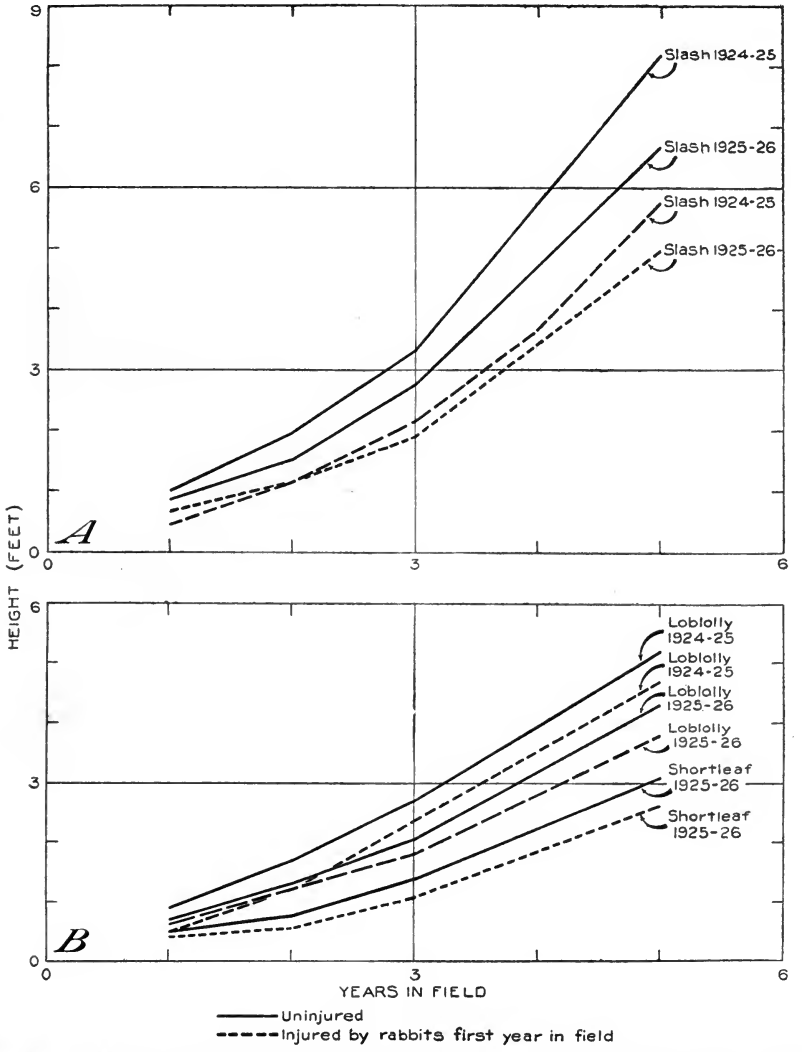

FIGURE 19.—Height growth of slash pine (*A*), and loblolly and shortleaf pine (*B*), planted in 1924–25 and in 1925–26, that was injured by rabbits at the beginning of the first growing season in the field, and of comparable stock not so injured. (Basis, in number of trees: 1924–25 plantation uninjured, 2,787 slash, 806 loblolly; injured, 749 slash, 240 loblolly. 1925–26 plantation uninjured, 518 slash, 826 loblolly, 749 shortleaf; injured, 206 slash, 32 loblolly, 94 shortleaf.)

pine have come to the attention of the Southern Forest Experiment Station, and neither of these was substantiated by collection and identification of specimens. It does great damage to Sonderegger pine, which is a hybrid between longleaf and loblolly pines.

The fact that longleaf and slash pines are practically immune to tip-moth injury apparently is due to their rapid flow of resin from injured tissues.

Infestation is usually heaviest on pines 1 to 8 feet high. In ordinarily dense stands, one attack upon leaders at points between 10 and 15 feet above the ground may deform the trees more seriously than several successive attacks at points below 8 feet. Open-grown trees are most heavily infested while 1 to 15 feet high.

The moths lay their eggs on the elongating shoots and newly exposed needles of the pines. The eggs hatch in a few days, and the larvae burrow first into the bases of the needles and then into the shoot itself, which they hollow out and kill. They pupate in the twig. When it is time for emergence the pupa works its way out of the twig, frequently through a pitch blister near the tip. During the

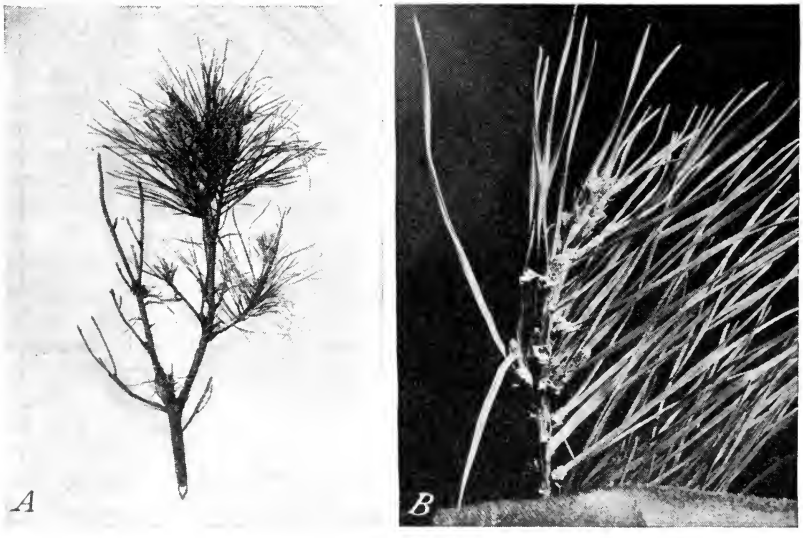

FIGURE 20.—*A*, Typical example of injury to loblolly pine by the Nantucket tip moth (*Rhyacionia frustrana* Comst.); *B*, adventitious buds of loblolly pine arising from the centers of the needle fascicles after injury to the twig by Nantucket tip moth.

flight of the adults minute, brown, empty pupae cases can be found clinging to the tips of many of the twigs. The adults are about one-eighth inch long; their wings are steeply sloping, fringed at the end, silvery in color, and irregularly crossbarred with brown. In color they match almost perfectly the sheaths around the bases of the needle bundles of loblolly pine, and they frequently hide upon these sheaths.

The insect produces four broods a year in the Gulf States, and possibly throughout the southern pine region. The combined work of these four broods may kill back young loblolly or shortleaf pines from 1 to 3½ feet each year. Notwithstanding their great vigor and rapid height growth these species cannot make much headway against such attacks, especially as much of the vigor of attacked trees is wasted in developing side branches and witches'-brooms (fig. 20, *A*). The trees would be killed back even more severely were it

not for the southern pines' remarkable faculty of developing new leaders from the centers of the needle fascicles at the highest portion of the twigs remaining alive (fig. 20, *B*).

It is commonly observed that tip-moth injury is greatest in large, pure, even-aged plantations, and in planted or natural stands on old fields, particularly those on soil which is not especially adapted to loblolly and shortleaf pines. On land formerly in longleaf pine where the subsoil is stiff and lies only a few inches beneath the surface, planted loblolly pines attacked by tip moth are so seriously killed back that planted or even naturally regenerated longleaf pines of the same age overtake them by the time they are 10 years old. On deeper and more penetrable soils, perhaps only a few feet away, loblolly pine planted or reproduced naturally makes much better height growth than longleaf pine in spite of tip-moth attack.

The effective methods of coping with tip moth, it appears, are to confine loblolly and shortleaf pines to the soils best suited to them, to keep pure, even-aged plantations of these species small and widely separated, and to plant at close spacing, 6 by 6 feet or closer, in order that side branches may be shaded off and stems straightened after injury. It appears desirable, also, to plant loblolly or shortleaf pine in brush or to mix with them species resistant to tip-moth attack, in order to force natural pruning and to reduce the food supply available to the tip moth. In small plantations the moth may be controlled in the egg stage by spraying the stock with either a 2-percent solution of Volck concentrate, or with nicotine oleate, using 1 part nicotine to 200 parts of water as recommended by the Bureau of Entomology and Plant Quarantine. Where nursery stock is dipped before shipment, care should be taken to prevent the solution from coming in contact with the roots.

Observations in plantations established by the Southern Forest Experiment Station in 1923, to study effects of various spacings, indicate great individual differences in the resistance of loblolly pines to tip-moth attack, even at the same spacing, and it may be possible to isolate a resistant strain.

Young plantations of all species of southern pine are sometimes defoliated by the larvae of LeConte's sawfly (described on p. 59) and other sawflies, and by adults of a small brownish beetle tentatively identified as *Colaspis brunnea* (Fab.). These insects appear over relatively small areas but in considerable numbers, and partly or entirely defoliate many trees. They are voracious feeders. Where spraying is feasible they are easily controlled by applying arsenate of lead according to the formula given in the appendix (p. 112). Outbreaks should be fought as soon as discovered, because a relatively small investment for spraying on areas up to 10 acres may prevent much more serious outbreaks later in the same season or in the following year.

Other insects to be guarded against in plantations are scale insects of the genera *Toumeyella* (described on p. 59) and *Chionaspis*. The *Toumeyella* scale appears largely on the twigs, and the *Chionaspis* almost exclusively on the needles. Large outbreaks have not yet been reported, but these insects are potentially dangerous to plantations and it is well to clear up any small, readily accessible infestations by spraying with miscible oils or nicotine sulphate.

Larvae of the genus *Tetralopha* (previously referred to as a nursery pest) frequently attack planted seedlings, particularly of longleaf pine. This insect has been noted most abundantly in Florida, but occurs throughout the Gulf States. It has done its greatest damage on the deep sands in western Florida and in the area of relatively low rainfall in eastern Texas. It lives in a tube of webbing and frass anchored to the top of the seedling. Ordinarily it injures only a few needles, but on small seedlings and under adverse conditions the loss of even a few needles sometimes prevents survival. No attempt has so far been made to control this insect on a commercial scale, but in view of its feeding habits, arsenate of lead is suggested as a possible means of control.

Among the most important diseases of planted southern pines is brown-spot needle blight, discussed on page 59 as a disease of nursery stock. Longleaf pine seedlings are highly subject to brown-spot attack, particularly between the time when the first fascicled needles appear and the time when the actively functioning foliage is 18 inches or more above the ground. Needles growing 8 or 10 feet above the ground sometimes show occasional or moderately abundant lesions. Slash pine also is attacked, particularly on dry sites or in localities outside its natural range where rainfall is lower and the evaporation rather higher. The hybrid Sonderegger pine is very severely attacked on some sites. Loblolly pine suffers from a disease that is thought to be brown-spot needle blight but has not been positively identified. Brown spot causes partial or complete defoliation, especially of longleaf pine, causes delay in height growth and sometimes severe stunting, and may cause serious mortality. It is least abundant on areas recently burned over (*26*), in exceptionally dry seasons, and on seedlings widely spaced. It is a moot question whether freedom from brown spot obtained by burning, even during seasons in which fire does little damage, completely offsets the damage done by the fires themselves. The disease is most severe on very densely crowded longleaf pine seedlings (200,000 to 300,000 per acre), where soil is too poor to support a protective covering of grass, and on seedlings that have not yet begun height growth.

In many localities brown-spot infection does not appear to be a great detriment to the success of longleaf pine plantations. If seedlings are kept free from the fungus in the nursery, those of high grade make such a vigorous start that infection during the first year or two in the field does not later prevent them from getting above the height—18 inches or a trifle more—beyond which danger from brown spot is negligible. In some localities and on some sites, however, where the disease is severe and seedling growth naturally poor, brown spot may cause high mortality and delay height growth of surviving trees for many years, unless artificially controlled.

In this connection it is significant that the better the quality of the longleaf pine seedling, as to development of taproot, foliage, and bud, the later it begins growth in the spring and the faster its needles develop once they have started. In a study of 200 seedlings of the same age at Bogalusa, La., in 1930, the seedlings possessing definite winter buds covered by white bud scales did not put forth new foliage until April, but the poorest seedlings, which had no bud scales at all, did so about the middle of February. Distinct brown-spot lesions

appeared on the new foliage of the poorest seedlings before the new needles of the best seedlings became visible. Thus the poorest seedlings suffered one complete cycle of the disease before the best seedlings were infected at all. The foliage of the best seedlings developed so much faster than that of the poorest that by the middle of June the average length of the needles on the best was greater than that of the needles on the poorest, despite the 2-month greater age of the latter.

What may prove to be a serious twig canker occurs on slash, loblolly, and shortleaf pines, but not, so far as is known, on longleaf. This disease first attracted attention in 1932, although examination of the cankers has shown clearly that it must have been in existence on southern pines at least as early as 1925 or 1926. In 1933 the disease was found in practically every State in the southern pine region. The worst infection thus far described has been in slash pine plantations in Georgia, where the disease has killed some trees outright and severely injured the crowns of many more. The fungus causing the disease has tentatively been identified as *Atropellis* sp.

FIGURE 21.—Gall of *Peridermium cerebrum* approximately 1 foot above the ground on trunk of 8-year-old planted slash pine.

Two other diseases to which planted southern pines, with the possible exception of longleaf, are somewhat subject are stem galls caused by *Peridermium cerebrum* (Peck) and *P. fusiforme* (A. and K.). These fungi are true rusts. Their alternate hosts are various oaks, particularly those growing on moist sites. The fungi attack planted pines from those 2 years old to those old enough to produce merchantable products, killing some and deforming others (fig. 21). The potentialities of these diseases are unknown. In one 8-year-old plantation of slash pine 3 percent of the trees were found to be infected, and loblolly pines in a 20-year-old natural stand have been observed to be infected at points 1 to 20 feet above the ground and deformed by galls 1½ to 2 feet in diameter. It is possible that the diseases are serious enough to furnish another argument for mixing longleaf pine with pines of the three other species.

Longleaf pine when first planted is subject to injury by silting, that is, by washing of sand and surface soil onto the almost stemless bud. This mishap, commonly resulting in death or in retardation of growth, can be avoided by using large, vigorous planting stock,

by planting directly in the rough or in well-settled hoed spots instead of in furrows, by avoiding burning of the planting site, and by "setting up" the seedlings as described on page 92.

Wind throw sometimes causes serious losses in young plantations of slash pine, apparently because of a combination of wet soil, shallow root habit, and doubling up of the roots in the slit in the process of planting. It is particularly likely to occur when the foliage is loaded with sleet, and may limit artificial extension of the range of slash pine northward.

Frost heaving causes little trouble in plantations in the southern part of the southern pine region, but is a serious problem in the piedmont plateau, the Ozark Mountains, and the Coastal Plain north of South Carolina. It can be avoided wholly or in part by planting in the spring instead of in the fall, by confining plantations to well-drained sites, and by using large stock. It is thought that using a planting bar instead of a mattock decreases frost heaving, but the point has not yet been demonstrated.

Injury done by competing vegetation has been discussed in connection with planting-site preparation. Where serious competition from other vegetation seems likely, it is particularly important to use high-grade planting stock. Southern pines other than longleaf, once established in the field, very soon outgrow the danger of injurious competition from vegetation that does not actually overtop them from the start.

SURVIVALS AND REPLACEMENTS

Failure of planted southern pine to survive well is usually explainable by one or more of the following: Poor planting stock, poor planting, adverse site, insect attack, fire, and drought. Of these factors drought alone is beyond man's power to modify, and even drought does its least harm to the best stock on the best sites.

With ordinarily good management any plantation of southern pine on good sites and in ordinary seasons should show a survival of 80 to 90 percent at the end of 1 to 5 years in the field. Except in the case of longleaf pine, the greatest loss usually takes place the first year. Between the second and the fifth to tenth years, mortality is likely to be higher in longleaf pine plantations than in plantations of the other species, sometimes because of the lingering death of seedlings injured by silting but more often because of brown spot or of competition from plants of other species. Survival of more than 95 percent at the end of the second or third year in the field has been recorded for several plantations of longleaf, slash, and loblolly pine.

Records of more than 300 separate southern pine plantations established by a great number of agencies in Florida before 1931–32 show survival either somewhat above 65 percent or very much below this percentage. From records kept by the Florida Forest Service on these plantations it is clear that survival well above 65 percent represents normal results with the species under reasonably favorable conditions, and that survival well below 65 percent represents, almost without exception, the effect of drought, fire, adverse site, or inept planting.

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Large places in plantations where practically all seedlings failed should be replanted unless the soil is clearly unsuited for the planting of any of the species available. If failures are distributed rather evenly throughout the plantation and the resulting stand is not too open to produce material of merchantable quantity or quality, it may be unnecessary to replace the dead trees. Ordinarily any plantation spaced fairly evenly 8 by 8 feet or closer need not be filled in if the survival is more than 70 percent. It is sometimes advisable to replace with another species, either better adapted to the site or more resistant to the injurious factors at work in the plantation. Failures in longleaf pine plantations may sometimes be replaced with slash pine when the survivors of the original planting are 3 or 4 years old. In that case the longleaf pine has a practically even start with the slash pine, and ordinarily will not be badly overtopped by it unless the site is much better adapted to the latter species.

In a series of experiments at Bogalusa, La., in which replacements were made in plantations of longleaf and slash pine, the mortality of the replacements was much higher than that of the original plantation. It was found that the failure of many of the replacements had been due to competition from brush and to the presence of roots of old stumps, or of hollows left by the decay of roots, within the root zone of the seedlings. In making replacements it may be well to plant a foot or two to the side of the spot on which a seedling of the original planting was unable to survive.

GROWTH

Too few plantations of southern pine have passed the age of 10 years to permit computation of useful growth and yield tables for planted stands as distinct from stands arising through natural regeneration. The few figures available are given in table 21. Comparison of these figures, particularly those for height, with figures for fully stocked natural stands indicates that plantations are well able to hold their own in rate of growth.

TABLE 21.—*Examples of growth of planted southern pine*

Species	Locality	Spacing	Time in field when measured	Height		Diameter	
				Average	Maximum	Average	Maximum
		Feet	*Years*	*Feet*	*Feet*	*Inches*	*Inches*
Longleaf	De Ridder, La.		21	35			
Slash [1]	Kirbyville, Tex.		6	15.6	23.3	2.8	4.5
	Clemson College, S. C.		8	17.0	20.3	3.2	4.2
Loblolly	Bogalusa, La.	5 by 5	10	21.0		3.4	
		6 by 6	10	19.7		3.5	
		8 by 8	10	19.9		4.0	
	Prince Georges County, Md.		13	40		6	
	Burlington County, N. J.		20		40	7.3	11.0
Shortleaf	Griffin, Ga.		35	52	60	11.5	14

[1] Both plantations were beyond the natural range of slash pine.

Longleaf pine is conspicuous for good growth in planted stands as compared with natural stands. The most remarkable instance so far noted is that of a small plantation in St. Tammany Parish, La. (fig. 22), in which the trees reached an average height of 10

feet when 5 years old from seed. The largest tree in the plantation at that age was 16 feet high and 3 inches in breast-height diameter. This plantation received no soil fertilization or other special care except that around every tree, to a radius of about 1 to 2 feet, a heavy

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FIGURE 22.—Exceptionally well-developed planted longleaf pine 5 years from seed, in St. Tammany Parish, La. The top of the handkerchief in the row to the right is 4½ feet above the ground.

mulch of pine needles was applied each fall and allowed to rot in place.

Several hundred acres of almost equally promising longleaf pine plantations have been observed near Sumter, S. C., but measurements from these are not available. The height distribution in a

much larger and more representative plantation of longleaf pine is given in figure 9, which also gives the height distribution in a better-than-average stand arising from natural reproduction and shows that the planted pine compares very favorably with that reproduced naturally.

The relative promptness of planted longleaf pine in beginning height growth as compared with that reproduced naturally is attributable largely to the superior development of the seedlings during their growing season in the nursery. Ten-month-old longleaf pine nursery seedlings of high quality are as large as wild stock 3 to 5 years old growing under good conditions. A further reason for rapid height growth in longleaf plantations may lie in the fairly wide spacing, which presumably has a restraining effect on the spread of brown spot needle blight. Preparation of the planting site by hoeing spots may contribute to the vigor of some seedlings. No experimental evidence available supports the hypothesis that pruning of the roots at the time of lifting and planting has a stimulating effect on height growth.

The course of development of a representative successful plantation of slash pine is shown in figure 23.

Future experimental work in artificial reforestation with all four principal species of southern pine should include efforts to segregate strains characterized by rapid and well-sustained height growth. That such strains exist may be inferred from many items of information already gleaned from studies of the southern pines.

RECORDS

Intelligent conduct of a planting program depends in great part on the technical records kept for each plantation. The record of establishment should include the following: Location (preferably in terms of section, range, and township); size (in acres); species; dates between which planting was done; preparation of site; planting method (tool, and any striking variations in manner of using it); character of planting stock (wild or nursery; age, size, and quality); specific source of stock; and source of seed from which stock was grown (State and county in which collected or, if these are not known, dealer from whom obtained). Later records, the first of which should ordinarily be made when the trees have been in the field 1 year, should include survival percentage, average height, and principal injuries (causes and extent). The more complete the technical records, the more valuable they will be in connection with future operations.

Economical conduct of a large commercial operation requires accurate cost records, which should include the cost of stock, of site preparation, of planting, of protection (including fencing and any insect-control measures), and of any necessary cleanings or liberation cuttings made during the first few years after establishment.

Of utmost importance in the records of any plantation containing more than one species, or more than 5 or 10 acres of a single species, is a plantation map showing clearly species, methods of planting, and dates of planting. Replacements, with the same or with other species, should be indicated on this map with particular care. The map should be on a scale large enough to permit showing clearly

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FIGURE 23.—Representative good commercial plantation of slash pine in Washington Parish, La.: *A*, Four years after planting; *B*, 7 years; *C*, 8 years. (All views from the same platform, 12 feet above the ground.)

in detail the boundaries of areas occupied by individual species or species mixtures, in relation to natural features such as swamps and streams and cultural features such as roads. A scale of 4 inches to the mile is satisfactory for mapping large areas planted with one species at one time. If the pattern of plantations is complicated and full of detail, it is advisable to double this scale.

An extensive planting program is subject to weather variations from year to year, differences in site quality, fluctuations in planting-stock quality, and even changes in species used. To check the success of such a program requires something more than casual ocular observation. Perhaps the simplest way to check it is by means of staked plots in representative portions of each natural unit of plantation. Such plots can include one-fourth, one-half, or 1 acre each. They should be marked with stout permanent posts on which their numbers and, preferably, indications as to species, date, and method of planting are painted distinctly. The plots should be tied in by survey to some familiar section corner or some permanent feature of the landscape, and their location should be precisely indicated on the plantation map. Such plots afford a crude but frequently adequate index of survival and height growth in the entire plantation. They are preferable to line plots particularly for the reason that they form convenient units for computing volume of wood produced when the plantations approach merchantable size.

Under the Forest Service line-plot system for observing survival and early height growth of plantations, from 100 to 300 trees are staked out in each natural unit of plantation, or in each 50-acre homogeneous block if the area of the plantation approaches or exceeds 100 acres. These line plots run diagonally across the plantation, including, for example, the first tree in the first row, the second tree in the second row, and the third tree in the third row, so as to sample the work of as many different crews as possible. In order to identify the trees by number, on every tenth stake the number is marked.

Another means of keeping track of the development of a plantation consists in a series of photographs showing the same portion of the plantation, taken from the same station at 1-year intervals for the first 2 or 3 years and thereafter, ordinarily, at 5-year intervals. The position and direction of each view should be chosen with care when the plantation is first laid out, and if possible the same camera should be used for all successive pictures.

Unless plantation photographs are taken from a lookout tower or some other point from which the view cannot be cut off by growing trees, they should be taken from outside the plantation or looking down the aisle between two rows, not looking down over the top of a row or across rows, and the picture's center of interest should be not more than 50 feet from the camera. Preferably, the film or plate should be used in the vertical rather than in the horizontal position, lest later repeat pictures fail to show the tops of the trees.

The photograph stations should of course be marked with permanent posts, tied in to section corners or natural features, and indicated on the plantation map, with great precision.

It is an excellent plan to deposit duplicates of plantation-establishment records with public agencies interested in artificial reforestation

in the locality. As the plantations develop, especially if they are among the earliest in their particular locality, they will be of immense value to such agencies as guides and object lessons, and filing establishment records with the agencies will not only insure preservation of important data but also increase the plantations' experimental value to the lumber industry and the general public.

The Southern Forest Experiment Station, with headquarters at New Orleans, La., maintains a directory of forest plantations, which will guide it in selecting areas for studies on technical problems involved in improving the survival and growth of planted southern pine. The station will welcome establishment reports of any forest plantations in its territory or of any southern pine plantations elsewhere in the United States. Such records should include the information itemized in the first paragraph under the heading Records. A form suitable for transmitting this information will be furnished by the station on request.

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APPENDIX

FORMULAE FOR NURSERY BAITS AND TREATMENTS

POISONED BAIT FOR FIELD MICE

Mix 1 tablespoon of gloss starch in one-fourth teacup of cold water and stir into three-fourths pint of boiling water to make a thin, clear paste. Mix 1 ounce of powdered strychnine (alkaloid) with 1 ounce of baking soda, and stir into the starch to a smooth, creamy mixture free of lumps. Stir in one-fourth pint of heavy corn sirup and 1 tablespoon of glycerin or petrolatum. Apply to 12 pounds of wheat, or preferably steamed crushed whole oats, and mix thoroughly to coat each kernel. Barley or cracked corn may also be used.

Complete instructions for field-mouse control are given in Farmers' Bulletin 1397 (*27*).

POISONED BAIT FOR "SALAMANDERS", OR POCKET GOPHERS (GEOMYS)

Cut sweet potatoes in pieces 1 inch long and one-half inch square; wash and drain. Grind together in a mortar one-eighth ounce of powdered strychnine (alkaloid) and one-eightieth ounce of saccharin and sift the mixture slowly into 4 quarts of the dampened bait, stirring to distribute the poison evenly. Thrust an iron rod into the animal's runway, drop in a piece or two of the bait, and close the hole with earth.

Complete instructions for control of "salamanders" are given in Farmers' Bulletin 1709 (*9*).

CONTROL MEASURES FOR NEMATODES

Steam sterilization of soil infested with nematodes, where applicable, gives the best control and is recommended especially for seed and nursery beds. Chemical soil treatments have in no instance proved 100 percent successful, and give satisfactory results only in light sandy soils. The two most satisfactory chemicals known at present for soil treatment in the open are carbon disulphide and chloropicrin (often also called chlorpicrin). Both must be applied with caution—carbon disulphide is highly inflammable and chloropicrin is a war gas requiring the use of gas masks during handling. Both may have fertilizing qualities, so that larger returns will partly pay for the expense of treatment. Carbon disulphide should be applied 100 to 303 gallons per acre, buried in holes 6 to 9 inches deep, 18 inches apart each way, in staggered rows, two-thirds to 2 fluid ounces per hole. The holes should be covered after application; soil may be replanted 2 to 3 weeks later. Chloropicrin should be applied 253 to 380 pounds per acre, by burying one-sixth to one-fourth fluid ounce in holes 6 inches deep, 18 inches apart each way, arranged in staggered rows and covered. Planting should be delayed until odor has disappeared.

The most practical, least expensive, yet very satisfactory method of cleaning land infested with nematodes is to plant it for 3 successive years to an immune crop. Clean cultivation free from weeds is necessary for success, since weeds may be hosts of the nematode and carry it over the starvation period otherwise produced by the immune crop. *Crotalaria spectabilis*, especially, and *C. juncea* are recommended as immune crops for the control of the root-knot nematode. Various grasses such as timothy, perennial ryegrass, Para grass, fescue grass, redtop grass, rye, Florida and Mauritius varieties of the velvetbean, and Iron and Victor varieties of the cowpea may also be planted to starve out this nematode.

Careful digging and burning of all infested root material as soon as possible after harvest help greatly in cleaning infested land, and using clean tools and implements helps to prevent the spread of these pests.

POISONED BAIT FOR MOLE CRICKETS

Mix 1 pound of paris green, or 1 pound of calcium arsenate, with 20 pounds of cottonseed meal and moisten with cheap sirup. Scatter the bait about the nursery at nightfall, because mole crickets feed at night (*5*).

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POISONED BAIT FOR CUTWORMS

Wheat bran	pounds	50
Paris green or crude arsenic	do	2
Blackstrap molasses[15]	quarts	2
Water	gallon	[16]1

Mix the dry ingredients very thoroughly. Mix the water and sirup (if sirup is used), and add slowly to the dry ingredients until the bait is just moist enough to fall, when scattered, in lumps about the size of wheat grains. The bait seems to work better if allowed to stand a few hours before being scattered. It is well to scatter the bait late in the evening, so that it will remain moist until the worms, which ordinarily feed at night, have had a chance to eat it. Use 10 to 15 pounds of bait per acre of nursery (*10, 36, 37, 38*).

BRAN BAIT FOR GRASSHOPPERS

The following formula is recommended by the Bureau of Entomology and Plant Quarantine:

Coarse bran	pounds	100
Crude arsenic	do	5
Cane molasses	gallons	1½
Water	do	10 to 12

Mix to a consistency permitting scattering in small flakes. Scatter early in the morning, preferably before sunrise, as grasshoppers do not feed at night.

Lead arsenate is not an effective substitute for paris green in grasshopper bait (*5*), nor are calcium arsenate and sodium arsenate.

LEAD ARSENATE FOR SAWFLY LARVAE AND COLASPIS BEETLES

Lead arsenate (powder)	pound	1
Fish-oil soap, casein, or laundry soap	do	1
Water	gallons	25

NICOTINE SULPHATE FOR APHIDS AND RED SPIDERS

Nicotine sulphate (40 percent)	ounces	8
Fish-oil soap (or common laundry soap)	pounds	4
Water:		
For aphids	gallons	50
For red spiders	do	32

Spray thoroughly and forcibly, and repeat after about 10 days (*30, pp. 407, 414*).

KEROSENE EMULSION (SOAP FORMULA)[17] FOR SCALE INSECTS

Kerosene	gallons	2
Whale-oil soap	pound	½
or soft soap	quart	1
Water	gallon	1

Divide soap finely; dissolve in water by boiling. *Remove from fire* and add, boiling hot, to the kerosene. Agitate violently by spraying back on itself with a force pump. After 3 to 5 minutes' pumping the mixture should be perfectly emulsified, from one-third to one-half greater in bulk, and the consistency of cream. Dilute 1 part of emulsion with 15 of water for summer use on plant lice or for use on red spider and other mites. For use on scale insects, 1 part of emulsion should be diluted with 7 to 10 of water.

BORDEAUX MIXTURE (5–5–50), MADE WITH PREPARED POWDER

Commercial prepared bordeaux powder	pound	1
Casein	ounces	3
Water	gallons	5

[15] Some authorities say sirup is unnecessary.
[16] Or more, as needed.
[17] An emergency substitute for the more easily handled miscible oils.

HOME-MADE BORDEAUX MIXTURE

Copper sulphate crystals	pounds	4
Hydrated lime	do	5
Water	gallons	50

To make a large quantity of bordeaux mixture, or to make small quantities repeatedly, it is desirable to prepare in advance separate stock solutions of copper sulphate and lime, each about 1 pound to the gallon. To prepare a stock solution of copper sulphate, a weighed quantity of the commercial crystals, bluestone, is placed in a sack and suspended in a barrel or other wooden vessel containing 1 gallon of water for each pound of copper sulphate. If the copper sulphate is placed in the bottom of the barrel, it dissolves slowly even with frequent stirring. When dissolution is complete, the solution should be made uniform by stirring.

The stock solution of lime is made by simply stirring the hydrated lime into the water; it is best to do this on the day preceding use.

The common method of making bordeaux mixture in the field has been to dilute the required quantities of copper sulphate and lime separately, each to half the final volume required, and to pour them together into a third container, usually the tank of the sprayer. Both solutions should be well stirred just before mixing. The colloidal suspension obtained by this method of mixing breaks down very slowly.

To 50 gallons of bordeaux mixture prepared by these directions, add 2 pounds of casein.

USE OF EXOTIC SPECIES

Early efforts at artificial reforestation with exotics in the southern pine region included various attempts to establish Scotch pine (*Pinus sylvestris* L.) and maritime pine (*P. pinaster* Ait.). The seed of these species used evidently was very unsuitable as to strain. One attempt to introduce the latter species was made by Clemson College at Summerville, S. C., in 1912, with the assistance and advice of the Forest Service. The Forest Service itself began in 1911 a series of direct seedings of maritime pine in the central peninsula and on the extreme west coast of Florida, and later planted in these same localities maritime pine nursery stock, part shipped from a northern nursery and part produced locally. In Florida, also, the Forest Service planted some cork oak (*Quercus suber* L.) and made a painstaking attempt to establish several species of eucalyptus. By 1930 nothing was left of several hundred acres of exotics planted by the Forest Service in Florida except a few eucalyptus sprouts arising from the stumps of trees killed back by frost and a few sickly maritime pines from 2 to 20 feet tall.

No noteworthy effort to establish forest plantations of exotic species in the South was made by the Forest Service in the period 1916–26. In 1927 efforts were renewed to find an exotic pine adapted to the soil of the Choctawhatchee National Forest, Fla., an extremely coarse sand very low in moisture-holding capacity. The Southern Forest Experiment Station made an exhaustive study of the climatic conditions under which pine species throughout the world reach optimum development, selected for study about 60 species growing in climates somewhat resembling that of western Florida, and systematically tested all these species on a small scale. Most of the trials failed totally. The species giving greatest promise of initial success were Italian stone pine (*Pinus pinea* L.), Chinese red pine (*P. massoniana* Lamb.), Japanese black pine (*P. thunbergii* Parl.), and strains of *P. pinaster* Ait. obtained from Corsica and central Portugal. It is entirely too soon to predict whether these pines will develop into merchantable stands on the soil of the Choctawhatchee Forest. Himalaya longleaf pine (*P. longifolia* Roxb.), a three-needled pine of the Himalayan foothills, from many standpoints a most desirable species, is unable to endure the winter cold of the Gulf Coast States.

Various species of *Eucalyptus*, including species growing at higher elevations in Australia and species successfully introduced in California, were killed by frost when tested on the northern half of the Florida Peninsula and in southeastern Louisiana.

Tests of exotic pines have been made in western Florida, central and western Louisiana, and east-central Texas by collaborators of the Institute of Forest Genetics, of Placerville, Calif. This institute, which is studying the

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possibilities of breeding an extremely fast-growing pine, has tried in other parts of the South most of the species being tested by the Forest Service on the Choctawhatchee National Forest. With the exception of some of the species just listed as possibly successful, all the exotic pines it has tested so far have failed.

Many species of pine native to California and some exotic pines when grown or planted in the South have shown an extreme susceptibility to brown-spot needle blight.

NURSERY INSPECTION AGENCIES

The officials to be consulted for detailed information on nursery inspection, plant quarantines, and shipping regulations in the southern pine region are listed below. If seedlings are to be shipped from one State to another, officials of both the State of origin and the State of destination must be consulted.

State	Title of official or department	Address
Alabama	Division of Plant Industry	Montgomery.
Arkansas	Chief inspector, State Plant Board	Little Rock.
Delaware	State Board of Agriculture	Dover.
Florida	State Plant Board	Gainesville.
Georgia	State Board of Entomology	Atlanta.
Louisiana	State entomologist	Baton Rouge.
Maryland	do	College Park.
Mississippi	do	Agricultural College
North Carolina	Division of Entomology, Department of Agriculture	Raleigh.
Oklahoma	State nursery inspector	Oklahoma City.
South Carolina	State Crop Pest Commission	Clemson College.
Texas	Chief, Division of Horticultural Inspection and Quarantines	Austin.
Virginia	State entomologist	Richmond.

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Technical Bulletin No. 491 October 1935

UNITED STATES DEPARTMENT OF AGRICULTURE

WASHINGTON, D. C.

SOIL MOISTURE AND IRRIGATION INVESTIGATIONS IN EASTERN APPLE ORCHARDS[1]

By J. R. MAGNESS, *principal pomologist*, E. S. DEGMAN, *assistant pomologist*, and J. R. FURR, *assistant horticulturist, Division of Fruit and Vegetable Crops and Diseases, Bureau of Plant Industry*

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INTRODUCTION

In the central and eastern parts of the United States most of the orchards are grown without irrigation, the trees depending upon natural rainfall and the water-holding capacity of the soil for moisture supply throughout the growing season. Under these conditions the amount of water available to the tree that can be held in the soil within the root zone of the tree is of extreme importance. Periods of from 1 to 2 months when very little rainfall occurs during the growing season are of relatively frequent occurrence. Unless the moisture-holding capacity of the soil is sufficient to carry trees

[1] The writers wish to acknowledge the helpful advice and assistance of E. C. Auchter, principal horticulturist in charge, Division of Fruit and Vegetable Crops and Diseases, in planning and conducting these investigations. They wish particularly to express their appreciation to the American Fruit Growers, Inc., and to R. S. Dillon, both of Hancock, Md., who furnished the facilities of their orchards for these investigations. Without such facilities the investigations reported in this bulletin could not have been conducted.

through such periods, poor growth and development of fruit will result.

In the selection of locations for the orchards many factors in addition to soil must be considered. In many parts of the Eastern States the primary consideration has been to secure sites at sufficient elevations so that air drainage would be satisfactory and the frost hazard reduced. In many instances such elevated sites have relatively shallow soils with rock, shale, or hardpan within 2 or 3 feet of the surface. The root zone of trees in such soil is limited by the rock or hardpan, and the water-storage capacity of the soil is limited because of its shallowness.

On the other hand, orchards have sometimes been planted on relatively heavy soils with clay or similar impervious subsoils which afford poor drainage. During wet seasons the water table in such soils is likely to stand relatively near the surface, killing off the lower roots or preventing their penetration, and the root zone is confined to the upper soil layers. Trees on such soils will suffer also from water shortage during periods of prolonged drought because of the shallow-root system. The possible extent of the root system is therefore of great importance in determining the total amount of water that can be stored in the soil within reach of the roots.

Soils also vary greatly in their capacity to hold or store water. Several terms relative to the water-storage capacity of the soil should be familiar to the orchardist. The "field capacity" of the soil is the amount of water the soil will absorb against gravity, and this varies with the texture of the soil. The coarser the soil, in general, the lower the field capacity, while with finer textured soils, such as silt loams or clays, the field capacity or water-holding capacity is progressively greater.

Not all water in the soil is available for plant growth. All plants will wilt and are unable to take up additional moisture from the soil when there is still an appreciable amount remaining. The amount of moisture in the soil which is unavailable to the plant is termed the "wilting percentage." The work of Briggs and Shantz (*3*)[2], and of many other investigators since, have shown that this wilting percentage also varies with the texture of the soil, but it is substantially the same for all plants in the same soil. The amount of moisture remaining in the soil when plants wilt is generally greatest for the finer textured soils and least for the coarser, sandy-type soils.

The amount of moisture present in the soil above the wilting percentage is termed "available moisture" and represents that available for plant usage. The available water that can be stored in a soil also varies with the soil texture. In general, the greatest amount of available moisture can be stored in the finer soil types, such as silt loams to clay loams, while total possible available moisture becomes less as soils become progressively lighter. Consequently on thoroughly drained, fairly fine-textured or heavy soils the possible water storage per foot of depth of soil will be high, while on coarser textured, lighter soils it will be progressively lower.

The total quantity of water available for tree growth that an orchard soil will hold will therefore depend upon the texture of the soil and particularly upon the extent of the root system. Root

[2] Italic numbers in parentheses refer to Literature Cited, p. 36.

penetration in orchard soils in some regions may be as deep as 20 or more feet. Such soils, if of medium texture and if saturated to their field capacity during the winter months, will hold sufficient available water to carry the trees through a growing season even if little rain occurs. As the root zone is more and more limited either by hardpan, rock, or high-water table, the storage capacity of the soil becomes progressively less and the period during which trees can thrive without rainfall progressively decreases.

It is not possible to determine exactly the quantity of water that an apple tree requires to carry it through a certain period without impairment of its normal functioning. Water is lost almost entirely by evaporation or transpiration from the leaf system. The quantity of water that a tree will transpire per day varies with the foliage area of the tree and with the evaporating power of the air. When temperatures are high and humidities low, particularly if there is wind, trees require the maximum amount of water. On the other hand, during a day when the humidity is high and the temperature moderate, trees will use relatively little water.

Beginning in the spring of 1930, experiments were outlined to study the relation of moisture supply to production of apples under climatic conditions prevailing in the Middle Atlantic States. The purposes of this work were to determine how frequently trees on different soil types may suffer for lack of water, the effect of such water shortage on growth of tree, growth of fruit, color, quality, and yield of fruit, on fruit-bud formation, on the physiological functioning of the tree, and the value of irrigation in correcting these effects of deficient moisture supply.

OUTLINE OF EXPERIMENTAL WORK

As a basis for these investigations, plots were laid out under three soil conditions in a commercial apple orchard near Hancock, Md. Water for the experimental irrigation of these plots was available from a large spring and was delivered to the plots through a stationary spray pipe system. Water was applied to all irrigation plots by the overhead sprinkler system. Experiments outlined were as follows:

Block A.—These plots were laid out on a very shallow, eroded silt clay soil underlain with shale at a depth varying from nothing to 18 inches. The plots consisted of York Imperial and Wealthy trees alternating in each row. The soil was so shallow that tree growth and production had been limited. The trees were approximately 22 years of age at the start of the experiment but were not more than half the size of well-grown trees of that age. During dry seasons the fruit from these trees had been unmarketable because of small size. This plot represented an extreme condition of shallow soil for apple production, and the plots were designed to determine whether trees on such soil could be made satisfactorily productive through irrigation.

Two plots consisting of 16 trees each were laid out. Both of the plots were seeded to alfalfa, one irrigated and the other nonirrigated. Because of the limited water-storage capacity in the shallow soil, the need for water was so frequent on these plots that it was impracticable in these tests to keep the so-called "irrigated plot"

thoroughly watered. Growth condition and production have been improved by the water applications made, but not sufficiently to secure good commercial crops. Because of the extreme condition of these plots and the devitalized condition of the trees at the start, detailed records are not presented.

The evidence obtained would indicate that on such very shallow soils, irrigation at intervals of not more than 10 days would be required during drought periods to keep apple trees functioning at near capacity. Land of this type will seldom produce profitable fruit crops without irrigation, and installation of an irrigation system would be justified only if water could be applied very cheaply. Such soils must be considered as submarginal for apple growing in any region where droughts even of relatively short duration are likely to occur.

Block B.—The soil of these plots is a silt clay containing considerable fine rock underlain with shale at a depth of approximately 2 feet. The varieties were Rome Beauty and Oldenburg (Duchess) alternating in each row. The trees were about 22 years old at the start of the experiment but were below normal in size because of the rather shallow soil in which they were growing. Four plots consisting of 16 trees each (approximately half each of Rome Beauty and Oldenburg) with two buffer rows between plots were established. Two of these plots were given a heavy wheat-straw mulch in the spring of 1930, and additional mulch was applied in the spring of 1932. This mulch, about 8 inches deep, was sufficiently heavy to keep down all weed growth around the trees. One plot, termed "irrigated mulch", was watered as required to prevent moisture from becoming the limiting factor in tree functioning at any time during the growing season. The second plot, termed "nonirrigated mulch", received only natural rainfall.

The other two plots were thoroughly cultivated each spring and were allowed to grow up to grass and weeds after the spring cultivation. One of these plots, termed "cultivated irrigated", received irrigation at the same time as the irrigated mulch. The second plot, termed "nonirrigated cultivated", received only natural rainfall.

Block C.—Plots in block C were laid out in an orchard of York Imperial trees growing in a deep clay loam soil. These trees were approximately 22 years old at the start of the experiment and were extremely large for their age. Excavations 6 feet deep revealed some root distribution throughout that area. Additional penetration with soil tubes to 12 feet deep showed no hardpan within the 12-foot zone. It is not certain how much below 6 feet deep root penetration occurred.

Four plots were laid out in this orchard, two of which were maintained in grass mulch which was mowed at intervals during the summer. One of these plots received irrigation at intervals, the other received natural rainfall only.

The two additional plots were thoroughly cultivated in the spring and allowed to grow to grass and weeds following the spring cultivation. One of these plots also received irrigation, the other received only natural rainfall.

The plots in these three locations established in the spring of 1930 have now been carried through four growing seasons under

the same type of treatment, thus permitting a study of the cumulative effects of irrigation or of water shortage.

In addition to these, other plots were started in the springs of 1931 and 1932, respectively, each being carried through only one season. One of these additional plots started each spring was irrigated, and the other was nonirrigated. These plots were used for the purpose of studying the immediate response of trees from conditions of variable moisture supply without the hold-over effects of differential treatments during previous years. These additional plots will be described in connection with the presentation of data obtained from them.

All trees throughout all the plots have received each year from 8 to 10 pounds of nitrate of soda per tree, applied about the time of

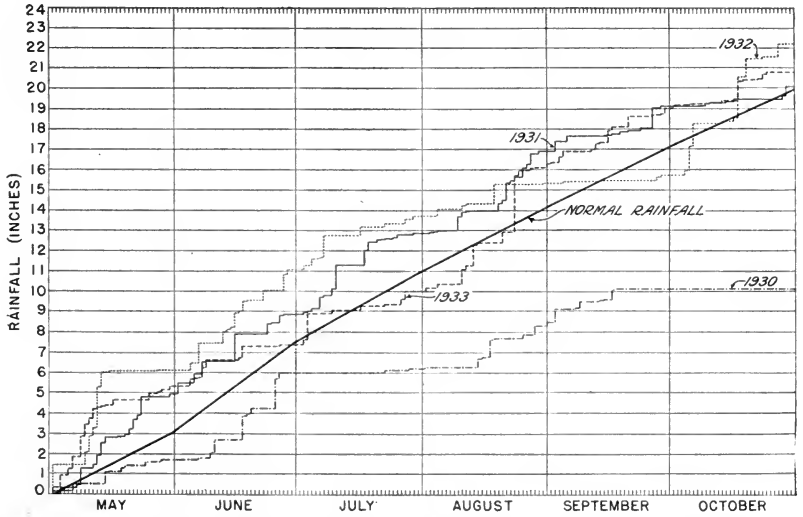

FIGURE 1.—Cumulative rainfall curves for the four growing seasons, 1930–33, inclusive. Data from May 1 to October 31, inclusive, obtained from United States Weather Bureau station at the orchard near Hancock, Md., where most of the experimental plots were located.

start of growth in the spring. The nitrate was distributed throughout the area from the trunk to slightly beyond the spread of the branches.

RAINFALL CONDITIONS DURING INVESTIGATIONS

Summaries of the rainfall during the growing season for each of the 4 years, together with the normal rainfall curve, are shown in figure 1. During the growing season of 1930 rainfall during May was approximately half of the normal. Rainfall during June was above average. From June 29 until August 14 practically no rainfall occurred. The weather during this period was extremely hot and dry. From August 14 to 18 approximately 1½ inches of rainfall occurred, with rainfall approaching normal until September 17. From that date until the end of the growing season no additional rainfall occurred. Rainfall from May 1 until October 30 totaled only 10.1 inches as compared with normal of 19.97 inches.

During the growing season of 1931 the total rainfall was slightly above average and was fairly well distributed. The periods of greatest moisture shortage that summer were during the first half of August and again during October.

In 1932 above-average rainfall occurred during May and June, but July rainfall was below normal. Following a 1-inch rain on August 19, no additional rains of as much as one-fourth inch occurred for a period of 45 days or until about the harvest season on late varieties. This prolonged late-season drought, following below-average rainfall in July and early August, resulted in extremely serious conditions in nonirrigated trees except those growing in deep soil.

During 1933 rainfall was fairly well distributed, but it was below normal during June and July. Only light rainfall occurred between July 4 and August 10, and during this period the trees on shallow soil suffered appreciably. Heavy rains occurred between August 10 and 25 followed by showery weather until the end of the growing season.

RESULTS OF FRUIT-GROWTH MEASUREMENTS

Throughout the experimental work, the rate of fruit growth on the various plots was determined by tagging representative apples in June of each season and measuring the growth in circumference of these fruits at intervals of 3 or 4 days throughout the growing season. Fifteen apples on each of at least three trees of each variety in each plot were used. Growth increments on a volume basis considering the fruit as a sphere have been calculated. The actual volume of the fruit is somewhat less than the volume of a sphere having the same circumference as the apples measured. The deviation of fruit volume from that of sphere volume is, however, consistent within a given variety, and in all cases comparisons of growth rate of fruit were made within the same variety. Results of growth measurements on the plots in block B for the 4 years, 1930–33, are shown in figures 2 to 5, inclusive.

The data obtained from the irrigated and nonirrigated plots in 1930 are shown in figure 2; also, the soil moisture is recorded as obtained by sampling at intervals throughout the season. The indicated points on the curves represent moisture determinations made on composite soil samples taken to a depth of 2 feet from at least 12 locations per plot. Samples during 1930 were taken with shovels, the soil was screened to remove fine rock, and moisture was determined by drying at 100° C. The wilting percentage of the soil in these plots, as determined by growing sunflowers in sealed cans of the soil, was about 6 percent. Field capacity of this soil, as shown by samples taken about 2 days after irrigations, averaged about 22 to 23 percent. Thus the soil in these plots held approximately 16 percent of available moisture, an excellent soil from the standpoint of its water-holding capacity.

In experimental work in a region having frequent summer rains it is impossible to obtain a completely accurate picture of the soil-moisture conditions throughout the growing season. The curves for moisture in figure 2 are based on the actual determinations made. Between determinations, the curves are hypothetical, being

based on rainfall and irrigation data. For example, a rainfall of 1 inch, coming on dry soil, does not wet the soil uniformly, but rather raises a portion of the soil to the field capacity while the remainder of the root zone is not affected. It is not possible to present this complete picture in the moisture curves. However, the approximate differences between the irrigated and the nonirrigated plots are clearly shown.

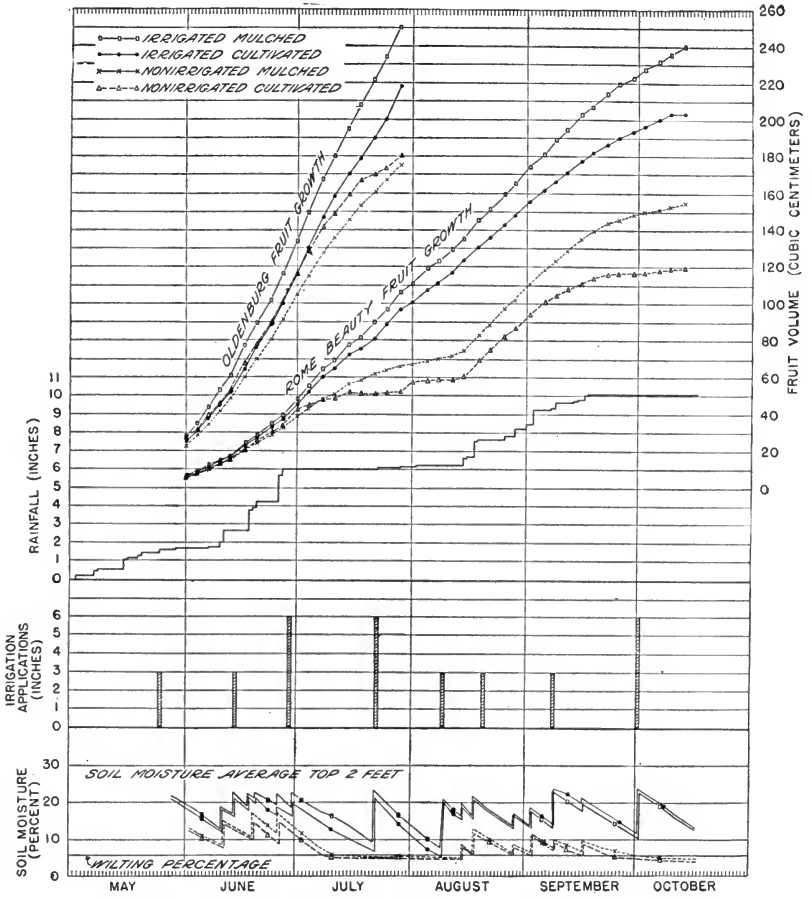

FIGURE 2.—Fruit growth, soil moisture, rainfall, and irrigation applications on Oldenburg and Rome Beauty plots, 1930.

The May rainfall during 1930 was limited. However, good rains occurred during June—a heavy rain on June 25, and a shower on June 26, totaling almost 2 inches. From June 26 to August 14 only three very light showers, totaling less than one-fourth of an inch, were recorded.

From the data in figure 2 it is apparent that by July 4 the fruit on the nonirrigated Rome Beauty trees in both the cultivated and mulched plots was growing at a much slower rate than that of the irrigated trees. The dry mulched Oldenburg apples were also growing at a slower rate than those on the irrigated mulched plot.

With the Oldenburg under cultivation, distinct differences in growth rate of the irrigated and nonirrigated fruit appeared by July 7. Thus within 9 to 12 days following the heavy rain on June 25 the fruit on all the dry plots was beginning to show reduced growth rate due to moisture shortage.

The Oldenburg apples in this experiment were picked on July 30. It was quite apparent prior to harvest, however, that as measured by fruit growth the Oldenburgs interplanted with the Rome Beauty trees were less seriously affected by the drought than were the latter. By July 30, fruit on the dry Rome Beauty trees was growing only

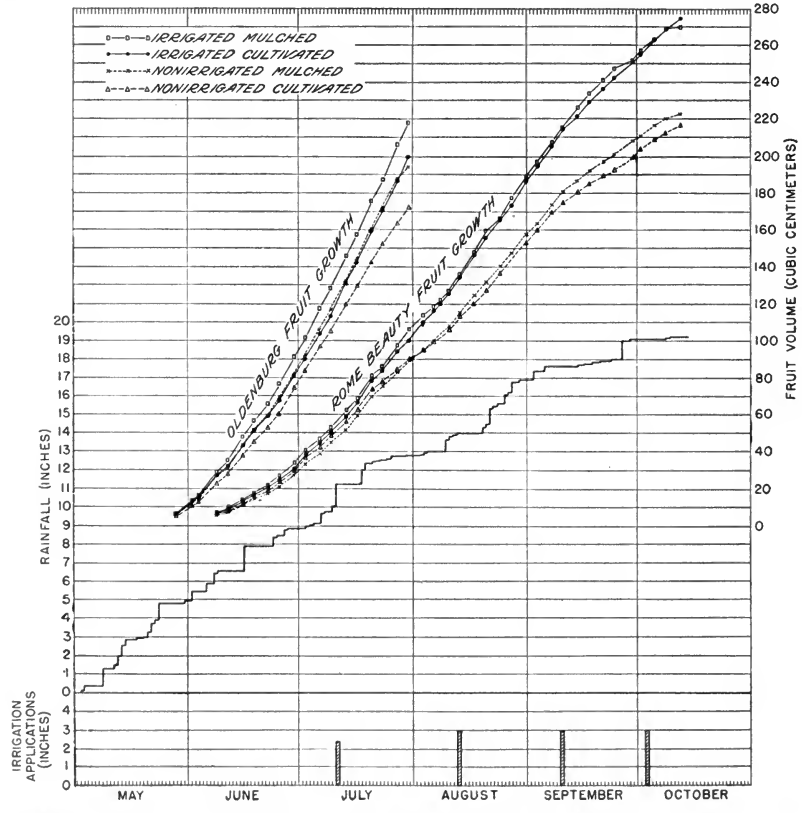

FIGURE 3.—Fruit growth, rainfall, and irrigation applications on Oldenburg and Rome Beauty plots, 1931.

approximately one-fourth as fast as on the irrigated trees, while the nonirrigated Oldenburg apples were growing at approximately half the rate of those on irrigated trees. Throughout the course of these experiments the Rome Beauty has apparently been somewhat more sensitive to moisture deficiency than has the Oldenburg.

During the period August 14 to 17 there was approximately 1½ inches of rainfall. Prior to this time the fruit on the nonirrigated Rome Beauty trees was making almost no growth, and the trees were approaching a permanently wilted condition. Following this rainfall and an interval of showery weather extending through the re-

mainder of the month the nonirrigated Rome Beauty apples grew almost as fast as those on the irrigated trees. Following a rain of approximately one-half inch on September 16 no further rain occurred until after the fruit was harvested on October 14. Within a few days the effects of this rain disappeared and the nonirrigated fruit was making little growth at the end of the season.

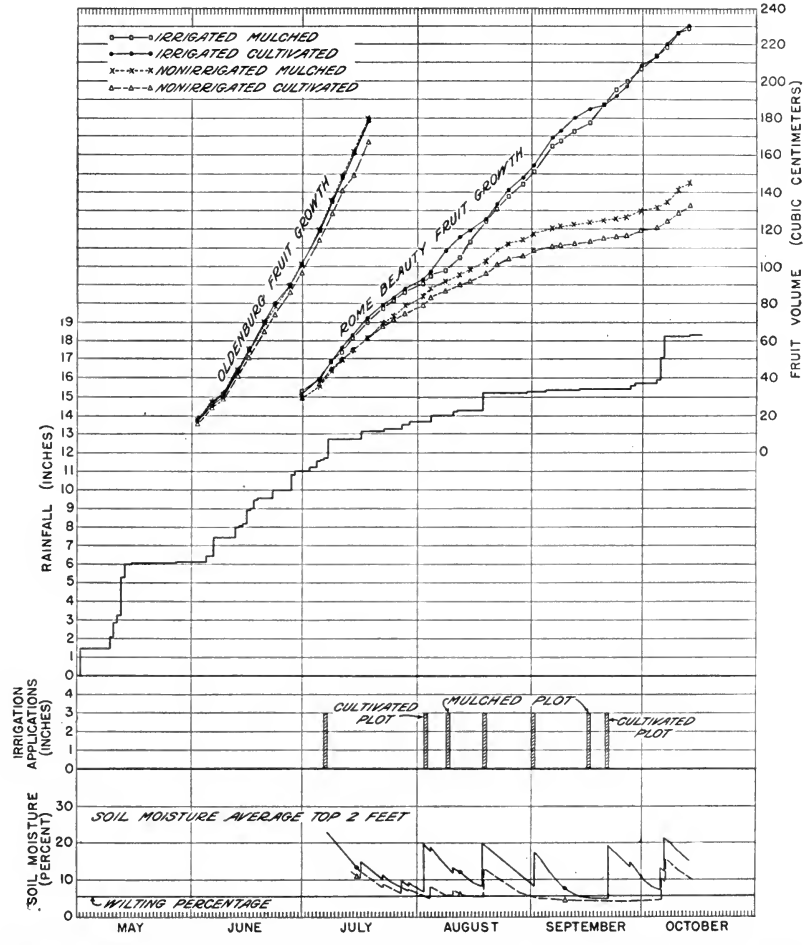

FIGURE 4.—Fruit growth, soil moisture on cultivated plots, rainfall, and irrigation applications on Oldenburg and Rome Beauty plots, 1932.

Typical Rome Beauty trees from the nonirrigated and irrigated cultivated plots on September 19 are shown in figures 6 and 7, respectively. The increased size of fruit and slightly denser foliage on the irrigated trees are evident from a close study of these illustrations.

Several points in the results for the 1930 season are particularly significant. According to the best records available on these heavily loaded trees, a reduction in the rate of fruit growth occurred while the average soil moisture in the root zone was somewhat above the

wilting percentage. Root concentration in these plots was very high in the surface foot, and it is practically certain that the soil moisture was down to approximately the wilting point in portions of this root zone before the growth rate was markedly affected by moisture supply.

A heavy irrigation of more than 5 inches of water was applied to the irrigated plots on July 21 and 22, 1930, which undoubtedly filled the soil to field capacity. No further irrigation was applied prior to the rain which started on August 14. A careful analysis of the

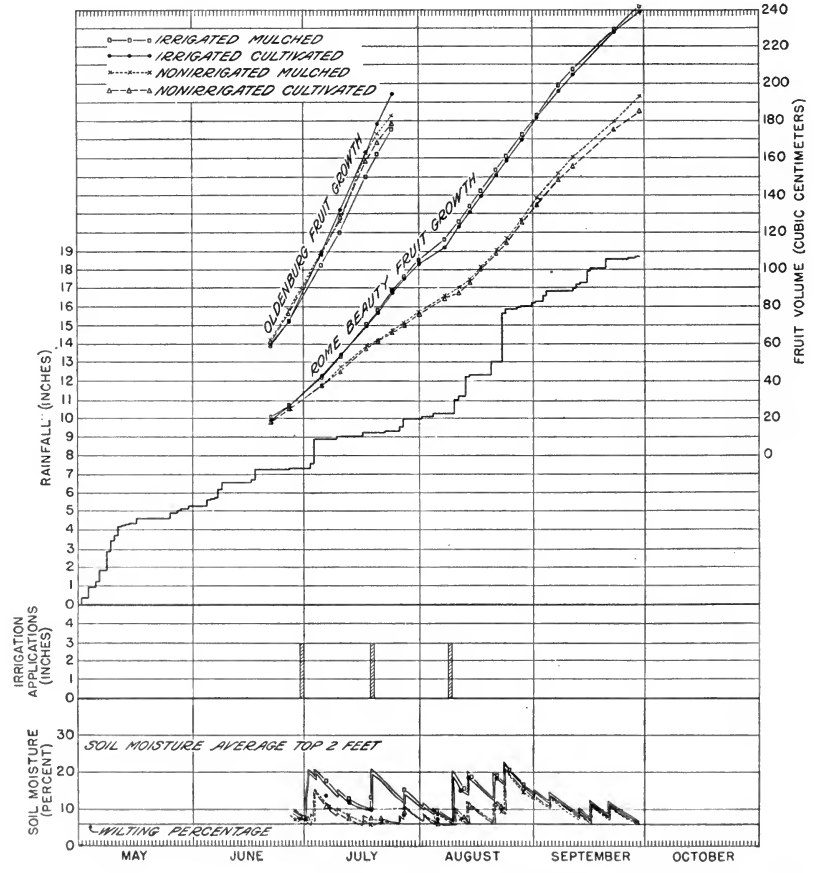

FIGURE 5.—Fruit growth, soil moisture, rainfall, and irrigation applications on Oldenburg and Rome Beauty plots, 1933.

growth curves of the irrigated fruit indicates that prior to August 14 the growth rate of this fruit had slowed down perceptibly. During this period temperatures were high, running over 100° F. during several of the days, with relatively low humidities. Under these rather extreme conditions the total water held by this soil was apparently only sufficient to carry the trees under optimum conditions for a period of approximately 25 days. Unless the soil moisture was at field capacity at the start of such a period of dry weather, the trees would suffer even earlier. Although such extremes of heat and

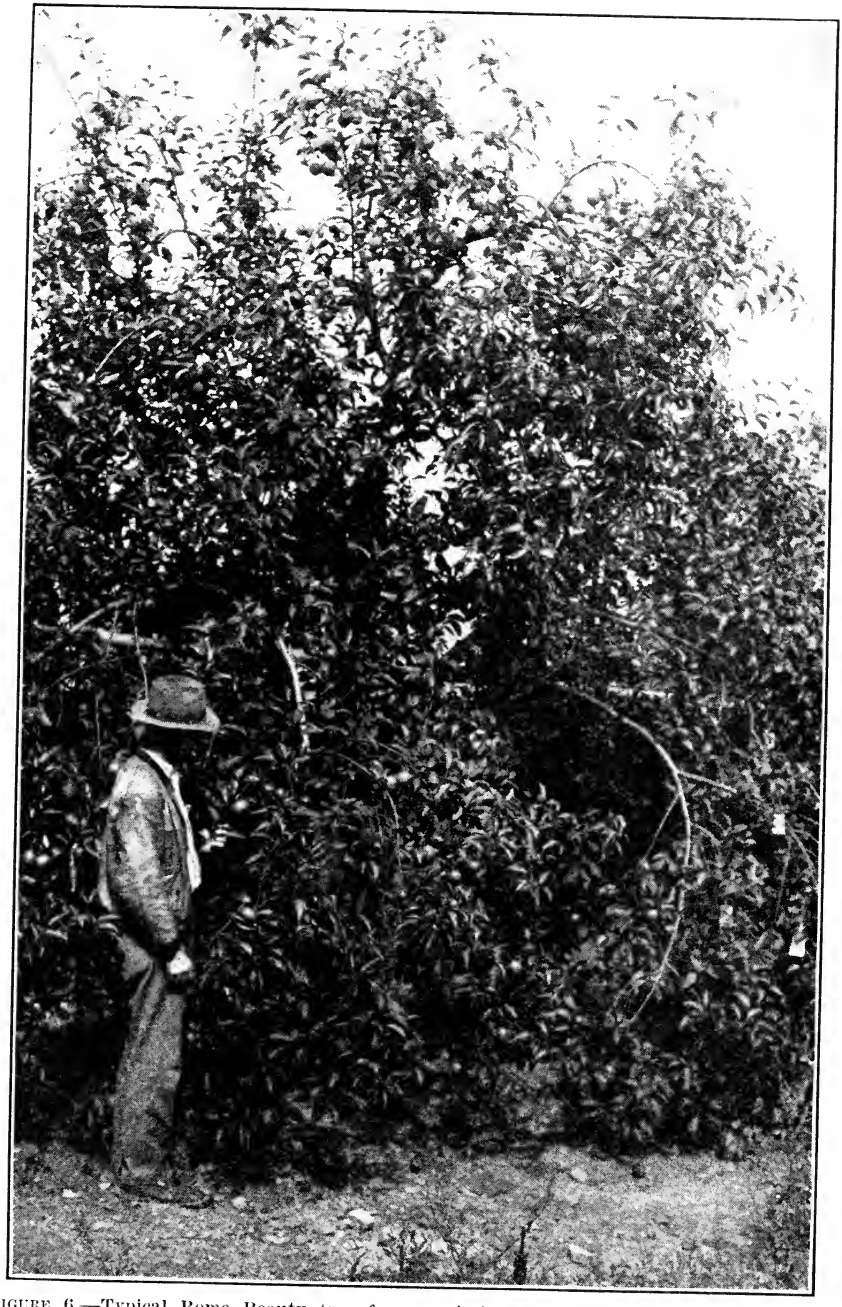

FIGURE 6.—Typical Rome Beauty tree from nonirrigated cultivated plot, photographed September 19, 1930.

FIGURE 7.—Typical Rome Beauty tree from irrigated cultivated plot, photographed September 19, 1930.

low humidity are rarely encountered in this section, these results with others obtained during the 4 years indicate that the water stored in these soils, 2 to 2½ feet deep, is only sufficient to carry the trees for a period of approximately 3 to 4 weeks. Since a period of drought is rarely encountered with soil moisture at field capacity at the start, reduction in growth rate of the fruit on trees on such soil is usually noticeable even during a relatively short period of dry weather.

By July 10 the soil moisture had reached the wilting percentage in the surface 2 feet of the nonirrigated plots and continued in that condition for a period of 35 days. Only a limited portion of the root zone could have been effective in absorbing water during that period. Oldenburg fruit on the nonirrigated plots between July 10 and picking date grew at approximately half the rate of the fruit on irrigated trees. The Rome Beauty apples on the nonirrigated mulched trees grew approximately one-third as fast as on the irrigated trees, whereas on the nonirrigated, cultivated trees growth was only about one-fifth of that on the irrigated trees. On a few individual trees, apparently in a permanently wilted condition, no fruit growth occurred during a part of this period. The results indicate that fruit growth will occur in apples until the tree is permanently wilted though the rate is greatly reduced as the moisture supply to the tree becomes very limited.

These plots have been carried through 3 successive years—1931–33. Growth data on the fruit taken each year in the manner indicated, together with the rainfall conditions and irrigation, are shown in figures 3, 4, and 5, respectively. Following the first season there was a distinct difference in growth condition of the trees during the spring of each year. Trees receiving irrigation during preceding years showed a more vigorous growth and a larger and more abundant foliage system. Consequently, following 1930, variation in size of fruit obtained each season, particularly with the Rome Beauty, can be attributed only in part to immediate differential moisture conditions that prevailed, and in part to the general vigor of the trees. This effect is shown particularly for 1931 in figure 3. During that year there was an excellent distribution of moisture throughout the season. There was a period of 3 weeks in late July and early August during which no heavy rains occurred, but light showers at frequent intervals kept the humidity high and reduced transpiration. There was, however, a rather definite decrease in growth rate of the Rome Beauty on the dry plots during early August which can be attributed to moisture shortage. Heavy rains occurred during late August and early September so that there was no time during that period when the nonirrigated trees approached the wilting percentage. Notwithstanding the fact that moisture was apparently available throughout the season with the exception of a short period in early August, there was a marked difference in the size of the fruit of the Rome Beauty and a slight difference in the size of the Oldenburg fruit at harvest time. These differences are probably due in considerable part to the better foliage on the more vigorous trees which had been irrigated during the previous season.

The results obtained in 1932 are shown in figure 4. The growing season of 1932 had above-average rainfall, as shown in figure 1, but distribution was very poor and trees on shallow soil suffered greatly.

Following heavy rains in May and June and a 1-inch rain on July 6 only light showers occurred until August 18. On that date a 1-inch rain fell, which was followed by a period of 46 days with no rain except very light sprinkles. The Rome Beauty in the dry plots showed a rather marked decrease in growth rate in early August, and in both the cultivated and the mulched plots the fruit growth was greatly reduced prior to the rain on August 18. The effects of that rain quickly disappeared, owing to the previously dry condition of the ground, and by September 1 growth of fruit on the dry plots had almost ceased. During September the fruit on the dry plots grew not over 20 percent as much as on the irrigated plots, and during the latter half of the month the trees were in a definitely wilted condition. Heavy rains occurring on October 5 resulted in fairly rapid growth of fruit in the dry plots during the last week of the growing season.

Notwithstanding the fact that 1932 had above-normal rainfall for the season, trees on shallow soil suffered under the conditions of this test even more seriously than in 1930. Nonirrigated trees in these experiments were definitely wilted during the last half of September and lost some foliage prior to the rains in October. Even under these extreme conditions, however, fruit growth was resumed at almost a normal rate when moisture again became available.

A full record of soil moisture throughout the season was not obtained in 1932. Curves based in part on actual moisture determinations, at points indicated, and in part on rainfall and irrigation data are shown in figure 4. Soil samples showed the moisture content of the surface 2 feet of the dry plots to be down to the wilting percentage on August 12. The 1-inch rain on August 18 restored available moisture for a few days and increased growth rate in the nonirrigated fruit. From August 28 to September 27, however, these plots were at or below the wilting percentage in the surface 2 feet and showed only very slow fruit growth.

On September 27 and 28 light rains occurred, totaling about 0.3 inch. Even these light rains increased growth rate in the dry plots for the 4-day period during which they occurred, as shown by the growth curves from September 27 to 30. While the effect of such light rains is quickly dissipated, the increased soil moisture, together with high humidity and decreased evaporation from the leaves, results in a temporarily increased fruit growth in trees suffering for moisture. As in 1930, appreciable decrease in the growth rate of fruit did not occur until the soil moisture approached within a few percent of the wilting point as an average condition. By that time a portion of the root zone probably had reached the wilting point.

The Oldenburg apples, harvested on July 18, 1932, showed no appreciable increase in size on the irrigated plots. Prior to the harvest date for this variety no period of moisture shortage occurred. Following good rainfall in 1931, all trees were in fairly good condition in the spring of 1932. The irrigated trees carried a somewhat heavier crop of fruit which attained equal size with that on the nonirrigated trees, perhaps because of the greater vigor of the irrigated trees.

Fruit-growth records for 1933 on these trees are shown in figure 5. During 1933 there was an unusually good distribution of moisture. Between July 3 and August 10, however, only a little over

1 inch of rain fell. During this period, growth of fruit on the dry plots was seriously reduced although showery weather and fairly high humidities resulted in a fruit-growth rate in the dry plots of Rome Beauty which was about two-thirds that in the irrigated plots. Following heavy rains in mid-August and showers throughout the remainder of the season, there was apparently no further period during which the nonirrigated trees showed indications of moisture shortage.

Following the extreme drought conditions of September 1932, the nonirrigated trees of Rome Beauty were much less vigorous in growth in the spring of 1933 and formed a smaller foliage system. Growth rate of the fruit on the nonirrigated Rome Beauty was somewhat less than on the irrigated trees in 1933, even when moisture was not a limiting factor, and notwithstanding the fact that the irrigated trees carried a heavier fruit crop (table 1). The Oldenburg trees, the crop of which was harvested prior to the drought period of 1932, were less seriously affected, and there was little difference in growth rate of fruit in 1933.

TABLE 1.—*Average yield of fruit per tree and per 100-cm² cross-sectional area of trunks, and average number of fruits per bushel during 4 years of irrigation and mulching experiments, block B*

Variety and treatment	Average yield per tree					Average yield per 100-cm² cross-sectional area of trunk					Fruits per bushel			
	1930	1931	1932	1933	Total	1930	1931	1932	1933	Total	1930	1931	1932	1933
Rome Beauty:	*Bu.*	*Bu.*	*Bu.*	*Bu.*	*Bu.*	*Bu.*	*Bu.*	*Bu.*	*Bu.*	*Bu.*	*No.*	*No.*	*No.*	*No.*
Cultivated nonirrigated	5.0	6.1	5.0	6.2	22.3	1.58	1.58	1.25	1.57	5.98	210	145	188	156
Cultivated irrigated	11.3	7.1	11.7	11.7	41.8	2.91	1.55	2.49	2.51	9.46	113	99	116	112
Mulched nonirrigated	6.8	9.7	7.2	7.4	31.1	1.59	2.06	1.32	1.59	6.56	164	130	155	126
Mulched irrigated	9.6	6.9	11.7	11.1	39.3	2.73	1.82	2.76	2.59	9.90	113	104	110	110
Oldenburg:														
Cultivated nonirrigated	5.7	6.8	3.7	4.1	20.3	2.01	2.13	1.04	1.12	6.30	183	153	119	149
Cultivated irrigated	7.5	4.5	6.3	3.6	21.9	2.74	1.41	1.86	.96	6.97	159	149	119	151
Mulched nonirrigated	6.4	6.5	6.1	5.3	24.3	2.04	1.92	1.29	1.12	6.37	168	137	116	151
Mulched irrigated	10.9	5.8	8.2	5.0	29.9	2.77	1.78	1.84	1.17	7.56	149	108	114	148

Although both the irrigated and nonirrigated trees in the mulched plots are in excellent vigor after 4 years of experimental treatment, the terminal growth is distinctly greater in the irrigated trees. Differences in the spring of 1934 would probably have been more pronounced had the growing season of 1933 been unusually dry.

YIELD AND SIZE OF FRUIT

The average yield of fruit per tree in bushels, the average yield per 100 cm² (15.5 square inches) cross-sectional area of the trunk of the trees, and the average number of fruits required to make a bushel for the four plots during the 4-year period are shown in table 1. Since there was some variation in size of individual trees, and since the yielding capacity of a tree is correlated with the size or trunk area of the tree, calculating yield data per unit of cross section of the trunk is believed to afford the most satisfactory basis of comparison.

From the data in table 1 it is apparent that the yield of the irrigated Rome Beauty trees per 100-cm² trunk area during the 4-year period has exceeded that of the nonirrigated trees by more than 54 percent. A comparison of these figures with the data on size of fruit (number of fruits per bushel) indicates that this increased yield was largely due to the increased size of the fruit each season on the irrigated trees as compared with those receiving similar cultural treatments but nonirrigated. The average size of the fruit on the irrigated cultivated trees was approximately 58 percent greater than that on the cultivated dry trees. Size of fruit on the mulched irrigated trees exceeded that on the nonirrigated mulched trees by approximately 32 percent. The average size of the fruit on the nonirrigated mulched trees was 21 percent larger than on the nonirrigated cultivated trees.

On the other hand, yield of fruit on the irrigated Oldenburg trees exceeded that on the nonirrigated trees in 1930, but the average of the 3 following years, 1931–33, inclusive, showed as high total yield per 100 cm² cross-sectional area of the trunk and almost as good average size on the nonirrigated as on the irrigated trees. Each year the Oldenburg crop was harvested no later than the last week in July. Only in 1930 did the trees suffer seriously from shortage of moisture prior to the time of harvest of the Oldenburgs, and this is reflected in the smaller size of fruit and smaller yields of Oldenburgs during that year. The Rome Beauty apples were not harvested until about October 10, thus showing the full effects of dry conditions through August and September.

The Rome Beauty trees showed on a 100-cm²-trunk-area basis a small but consistent increase in yield and size of fruit when mulched as compared with the similarly treated cultivated trees. This is believed to be due partly to slightly better moisture conditions under the mulched trees and partly to a slightly better growth condition because of abundant organic matter under these trees. The trees of the Oldenburg mulched and irrigated plot were more productive and the fruit averaged slightly larger than in the cultivated plot under irrigation. There was no significant difference between the dry cultivated plot and the dry mulched plot with the Oldenburg.

These results indicate that a variety requiring a long growing season, such as Rome Beauty, is much more likely to be benefited by irrigation than is a variety that ripens in midsummer, such as Oldenburg. Under the conditions of these tests the Oldenburg trees seemed to suffer slightly less than the Rome Beauty during drought periods when both varieties still carried their fruit. Since soil under eastern orchard conditions is likely to be saturated with moisture at the start of the growing season, varieties ripening in July or early August have a much better chance of reaching the fruit harvest season without suffering from shortage of moisture than do varieties that carry their fruit throughout the summer.

Results of tests with the Oldenburg indicate that these trees did not suffer greatly from drought conditions which prevailed after the crop was harvested. It has been observed repeatedly in these investigations that trees carrying very heavy crops of fruit suffer earlier and more severely than do trees carrying light crops or from which the fruit has been harvested. Similarly the benefits from

mulching have been more outstanding in the long-season Rome Beauty variety than in the early-ripening Oldenburg.

RESULTS OF 1-YEAR IRRIGATION EXPERIMENTS

GRIMES GOLDEN-DELICIOUS PLOT, 1931

During the summer of 1931 an additional series of plots for irrigation experiments was established in a block of Grimes Golden and Delicious trees in an orchard approximately 2 miles from that in which block B was located. These plots were established for the purpose of studying the effects of varying moisture conditions during the season of 1931 on trees that previously had not received differential moisture treatments. The trees were only about 12 years old but were relatively large for their age. Since the trees were planted only 22 feet apart, the roots occupied most of the available soil. The soil was 2½ to 3 feet deep above shale and was relatively free of rock. It was a moderately heavy loam with a field capacity of about 20 percent and a wilting percentage between 9 and 10. The trees had only a moderate crop with an abundance of foliage in proportion to the crop carried. All plots were thoroughly cultivated in the spring.

These plots were laid out on July 20. Prior to that time, through May, June, and early July, there had been an abundant, well-distributed rainfall. On July 27 a heavy hailstorm injured the fruit and foliage, but the records obtained on growth rate of fruit in relation to moisture supply accurately represent conditions as they existed. Rainfall data were obtained at a point approximately 2 miles away and are not strictly accurate for these plots, as some local storms (including the hail of July 27) occurred in the vicinity of the plots that did not occur at the place where the records were taken. Rainfall, soil-moisture, and fruit-growth data for both varieties are shown in figure 8.

According to these data, samples from the nonirrigated plots on August 12 indicated that the soil-moisture supply in the surface 2 feet was within 3 percent of the wilting percentage. During the following week no rain occurred, although the weather was moderately cool. During this period the growth rate of the fruit on the nonirrigated trees of both varieties was about 25 percent below that on the trees receiving irrigation. During the period from August 19 until September 16, rainfall totaled 3.6 inches and was well distributed. No additional irrigations were applied until September 17. The nonirrigated plots from September 17 to 25 were within 4 percent of the wilting percentage, whereas the irrigated plots were near field capacity. The weather was moderately cool with a few very light showers. During this period the fruit on the nonirrigated plots grew at about 80 percent of the rate of that on the irrigated plots.

These results indicate that with an abundance of foliage and during moderately cool weather the growth rate of the fruit was not reduced as a result of moisture shortage until the average moisture content in the surface 2 feet approached less than 5 percent of the wilting percentage, with portions of the root zone probably reduced to that point. During the period from August 20 to Sep-

tember 10 the moisture content of the irrigated plots averaged from 4 to 6 percent higher than in the nonirrigated plots, but the growth rate of the fruit was practically the same. The soil-moisture data in this experiment are based on samples taken at 12 different points about each tree and present a very accurate picture of the moisture conditions. On these nonirrigated trees during the season of 1931 the growth rate of the fruit was slightly reduced between

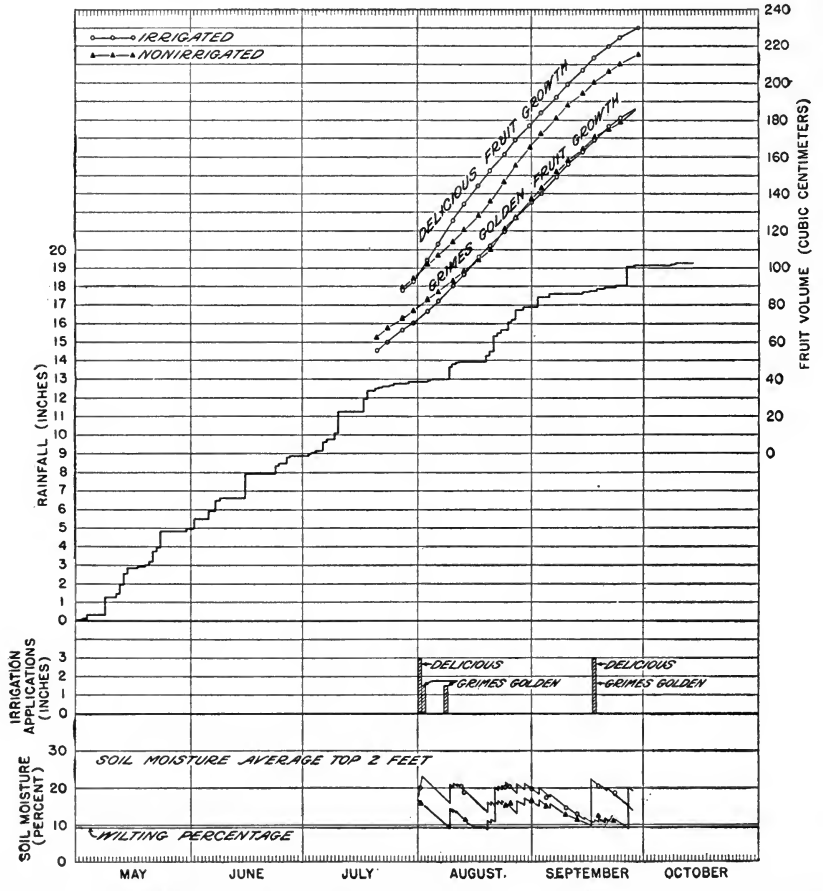

FIGURE 8.—Fruit-growth, soil-moisture, and rainfall record for Delicious and Grimes Golden apple plots irrigated for one season only, 1931.

August 1 and 17 and again between September 15 and 25, because of insufficient available water.

DELICIOUS PLOT, 1932

In early June 1932, a plot of Delicious trees which had not previously received differential treatment was laid out for moisture studies. These trees all carried a heavy crop, the nonirrigated plot carrying slightly more fruit on the average than the irrigated trees. Four representative trees were selected for detailed records, receiving only rainfall, and four other trees were irrigated as needed

through the season. These trees were about 18 years old, of fair size, and were growing in a stony, clay loam soil underlain with shale at a depth of approximately 2½ feet. The shale beneath these trees was somewhat dense and impervious. The field capacity of this soil was about 26 percent and the wilting percentage between 11 and 12. The plots were all cultivated in the spring.

The fruit-growth data for these plots, also the rainfall data and a partial soil-moisture record, are shown in figure 9. Prior to about July 10, the growth rate of the fruit on the irrigated and nonirri-

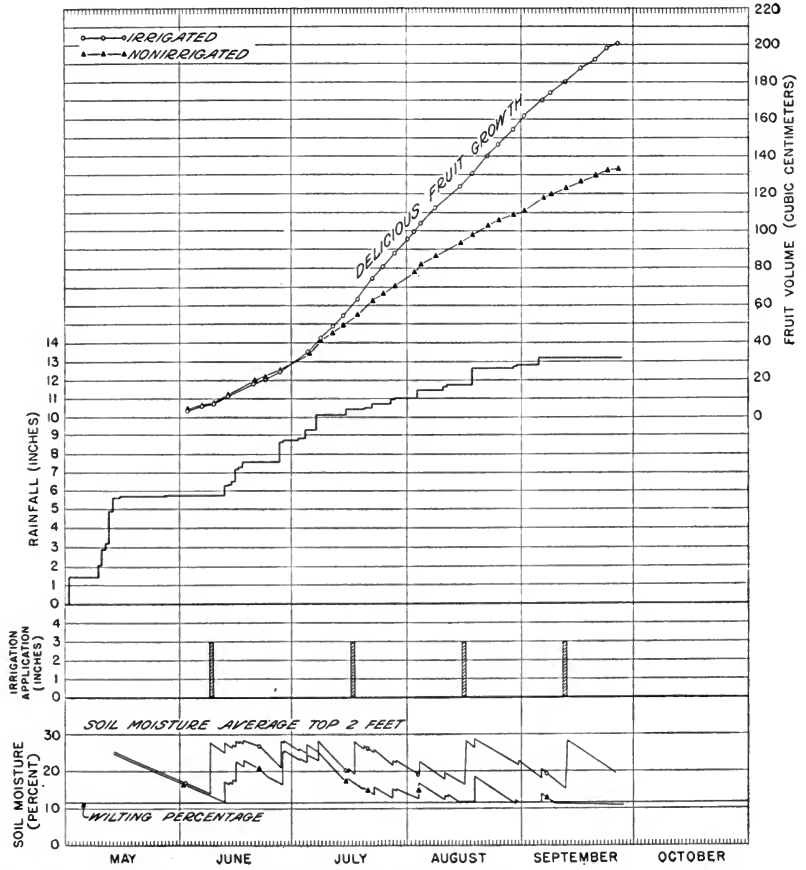

FIGURE 9.—Fruit growth, soil moisture, and rainfall record for Delicious apple plots irrigated for one season only, 1932.

gated trees was uniform. Following the 1-inch rain on July 7 only 3 inches of rain fell until the end of September or after the harvest period for this fruit. This limited rainfall was distributed through numerous light rains, as shown in figure 9. The fruit in the irrigated plots grew at practically a steady rate, which was much more rapid than that of the fruit on the trees in the nonirrigated plots. From August 1 until harvest the growth rate of the fruit from the irrigated trees was approximately double that of fruit from the nonirrigated.

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Although the growth rate of fruit from the nonirrigated plot was much below that of the irrigated, a slow growth occurred throughout the whole period even though little rainfall occurred from August 18 until the end of September. There is a possibility that these nonirrigated trees obtained a little moisture from near the shale rock, as trees about this dry plot were given partial irrigation by the owner of the orchard. It would seem that unless this occurred the nonirrigated trees would have made progressively slower growth through September. Soil-moisture data indicate that by September 6 the moisture in the surface 2 feet had practically reached the wilting percentage, and it remained in that condition until harvest time. Throughout the whole season the moisture content of the irrigated plot did not approach close to the wilting percentage. The total yield of fruit at harvest averaged 18.9 bushels per tree for the irrigated plot and 14.3 bushels on the nonirrigated. The number of fruits per bushel averaged 111 from the irrigated and 156 from the nonirrigated plots.

RESULTS IN BLOCK C

Trees in block C, consisting of large York Imperial apples growing in heavy, deep soil, were in an alternate-bearing condition. (See p. 4 for detailed description.) During 1930 these trees bore practically no crop. In 1931, on the other hand, a heavy bloom and good set of fruit occurred and the crop was uniformly heavy over all plots. The trees in the irrigated plots had received irrigation as needed during 1930, but detailed records for that year are not shown because the trees were not bearing. Results on fruit growth and rainfall in 1931 are shown in figure 10.

These results indicate that in 1931 the growth rate of fruit on nonirrigated trees in this deep, fairly heavy soil slowed down slightly as compared with that of irrigated trees between August 5 and 18. The growth rate during this period was 20 to 25 percent slower in fruit on nonirrigated trees. Again between September 10 and time of harvest on October 8, the growth rate of the fruit on the nonirrigated trees was about 25 percent below that on the irrigated plots. On August 5, moisture in the surface 2 feet of the nonirrigated plots was within 2 to 3 percent of the wilting percentage when measurable difference in growth rate was occurring. The moisture record obtained on these trees was very incomplete but indicated a slowing down in growth rate when the surface foot, in which the greatest root population occurred, approached close to the wilting percentage.

In 1932 these trees carried a light crop of fruit, and detailed fruit-growth measurements were not made. In 1933 they bloomed heavily, but owing to frost and unfavorable weather conditions during the pollination period, very little fruit set. The fact that during 4 years this plot of trees bore only one heavy crop and one partial crop makes the moisture-relation studies less significant than they otherwise would be.

During both of the particularly dry years of 1930 and 1932 these trees were carrying very little fruit. In neither year did they suffer seriously from moisture shortage. At the end of 4 years there was very little difference in appearance or growth condition between the

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trees that had been irrigated and those that received only rainfall. It is unfortunate, from the standpoint of these studies, that these trees did not carry a heavy crop during any particularly dry year. Observations on the trees, however, indicate that although the size of the fruit was reduced, the trees did not suffer seriously under the driest conditions that prevailed during the 4 years of these tests. Excavations indicated that these trees have roots at least 6 feet deep in a retentive clay soil though the main root population is in the surface 2 feet. Results of investigations by Aldrich and Work (*1*) on pears in very heavy soils at Medford, Oreg., indicate that on

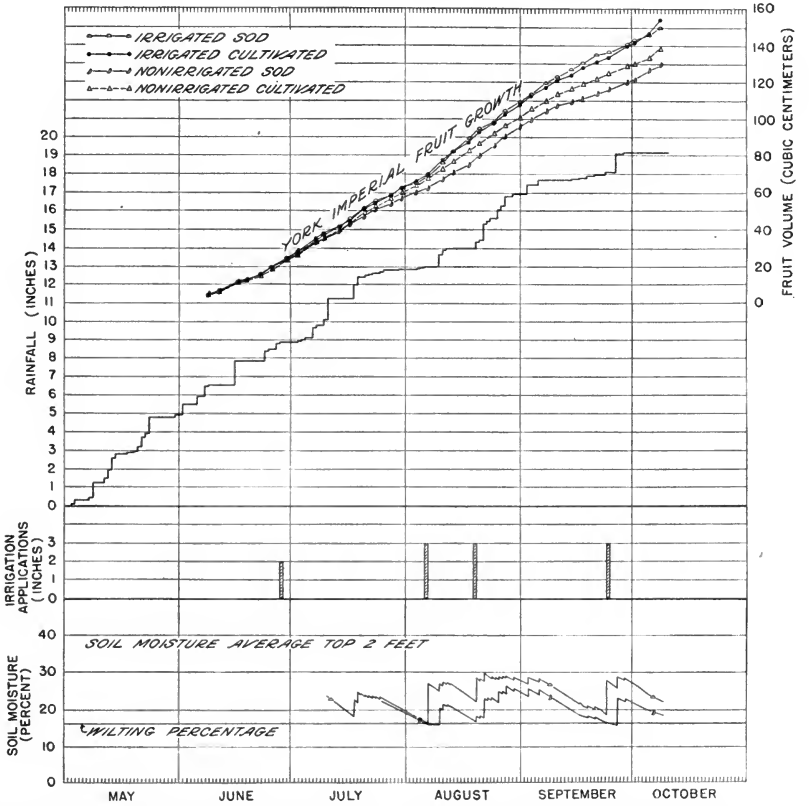

FIGURE 10.—Fruit growth, soil moisture, rainfall, and irrigation applications on experimental York Imperial plots, deep heavy soil, 1931.

such soils the growth rate of fruit decreases while the moisture content is still much above the wilting percentage. Results in 1931 indicate that, in the present tests, growth of fruit on these heavily loaded York Imperial trees was not reduced measurably until the moisture was fairly close to the wilting percentage in the surface 2 feet.

EFFECT OF MOISTURE SUPPLY ON COLOR DEVELOPMENT

Throughout the course of these experiments, records were made of the percentage of the fruit falling in various color classes at time of

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harvest. Color records obtained on the Oldenburg and Rome Beauty plots in 1930 and 1931 have been reported in detail by Fletcher (*5*). His report indicates that in both 1930 and 1931 the color of the Oldenburg fruit at harvest time was slightly poorer on the plots that had been irrigated than on the corresponding nonirrigated plots.

Records showing the amount of the fruit surface which became red for three Rome Beauty crops and for the Delicious in 1932 are summarized in table 2. In the Rome Beauty apples the area of the red color was slightly greater on the fruit from the irrigated cultivated plot in 1930 than on the corresponding nonirrigated plot. There was no significant difference in color of the fruit from the irrigated and nonirrigated mulched plots. The quality of the color in that year was much superior on the fruit from the irrigated plots, being a bright sparkling red, whereas on the nonirrigated plots the color was dull bronze-red and much less attractive. In 1930 the color of the fruit from the mulched plots was distinctly better than that from the cultivated plots.

TABLE 2.—*Effect of irrigation and cultural treatments on the proportion of fruit surface which became red*

Variety, year, and treatment	Percentage of crop in color class—					Average percentage of surface colored
	0–25	25–50	50–75	75–100	50–100	
Rome Beauty, 1930:						
Cultivated nonirrigated	24.7	39.4			35.9	44.6
Cultivated irrigated	25.9	26.1			48.0	48.0
Mulched nonirrigated	16.0	25.5			58.5	55.4
Mulched irrigated	20.4	22.2			57.4	53.9
Rome Beauty, 1931:						
Cultivated nonirrigated	19.8	39.5			40.7	47.7
Cultivated irrigated	20.4	43.8			35.8	46.6
Mulched nonirrigated	16.9	40.5			42.6	48.0
Mulched irrigated	42.8	33.5			23.7	35.6
Rome Beauty, 1932:						
Cultivated nonirrigated	22.5	33.5	22.3	21.2		47.9
Cultivated irrigated	22.1	31.7	22.2	25.0		50.4
Mulched nonirrigated	29.1	38.5	17.5	14.5		41.7
Mulched irrigated	23.7	28.7	19.6	26.5		49.1
Delicious, 1932:						
1-year plot—						
Nonirrigated	9.3	21.9	26.2	42.5		62.9
Irrigated	4.1	22.1	39.8	33.9		63.4

In 1931, a season of good rainfall and with moderately light crops on the trees, the area of the red color on the Rome Beauty fruit from the irrigated plots in each case averaged less than that on fruit from the corresponding nonirrigated plots. During that season there was not a marked difference in quality of color between fruit from the irrigated and the nonirrigated plots. The poorest color was on fruit from the mulched irrigated plots where the trees were very vigorous.

In 1932 the Rome Beauty, following three seasons of irrigation treatment, showed a slightly greater area of the fruit colored on the irrigated plots. The fruit on these plots was also very much brighter red and much more attractive in appearance. The nonirrigated trees were extremely dry during September, and the color of the fruit on these trees was dull and lifeless, even though the area of

the color was only slightly reduced. These results agree in general with those of Fletcher (*5*), also with color records reported by Overley, Overholser, and Haut (*14*) in Washington State, and with unpublished data which have been obtained by C. P. Harley and M. P. Masure at Wenatchee, Wash. During seasons of sufficient rainfall the application of additional irrigation water did not improve color but tended to decrease the area of the surface on the fruit that became red. On the other hand, during seasons when the fruit ripened with the moisture content of the soil at or very near the wilting percentage, the color development of the fruit was poor and dull as compared with that which received sufficient moisture. Apparently moisture available to the tree is essential to the highest color development, but excessive moisture in the soil is unfavorable and is likely to lead to poor color development.

Results were similar on the Delicious plots in 1932. The area of color was practically the same on fruit from the two plots, but the fruit from nonirrigated plots, which ripened with the trees suffering greatly for moisture, was dull and unattractive. Fruit from irrigated trees was a bright and clear red.

EFFECT OF MOISTURE SUPPLY ON FRUIT-BUD FORMATION

Throughout the course of these experiments, records were obtained each spring of the percentage of the growing points which formed blossoms and of the blossoms which set fruit. The total number of growing points and the total number of blossoms on from 6 to 8 branches 1½ to 2 inches in diameter well distributed over the tree, and representative of the estimated average condition of the tree as a whole, were counted each season. Percentage of flowering was obtained by dividing the number of blossom clusters by the total number of growing points of the branches. Percentage of set was the percentage of clusters that set fruit.

The average percentage of fruit-bud formation and fruit set on the Rome Beauty and Oldenburg trees through three seasons is shown in table 3. These results indicate that the average bloom was heavier in the dry plots in the spring of 1931 than in the corresponding irrigated plots. These results, previously reported by the writers (*4*), indicated that if the trees suffer appreciably for water during the period of fruit-bud formation, increased fruit-bud formation is likely to result.

Following the heavier bloom there was a heavier crop of fruit on the nonirrigated than on the irrigated trees in 1931. No moisture shortage occurred in 1931 prior to late July. In the spring of 1932 a heavier bloom occurred on the irrigated than on the nonirrigated trees. In the spring of 1933 the nonirrigated trees on three of the plots carried a slightly heavier bloom, though the mulched irrigated Rome Beauty had slightly more bloom than the nonirrigated ones.

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TABLE 3.—*Average bloom and fruit-set record in irrigated and nonirrigated apple plots, 1931–33*

Variety and treatment	Spring 1931		Spring 1932		Spring 1933	
	Bloom	Set	Bloom	Set	Bloom	Set
Rome Beauty:	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Cultivated nonirrigated	31.4	40.5	45.6	53.0	30.8	43.4
Cultivated irrigated	23.1	40.9	61.6	45.9	26.4	48.4
Mulched nonirrigated	28.2	51.7	47.1	60.8	15.5	55.5
Mulched irrigated	14.0	55.0	58.2	39.4	17.9	49.9
Oldenburg:						
Cultivated nonirrigated	48.5	49.6	43.2	79.2	74.3	31.2
Cultivated irrigated	24.0	54.4	53.4	72.4	48.1	56.6
Mulched nonirrigated	39.8	47.7	32.6	81.6	69.8	22.6
Mulched irrigated	28.7	43.6	39.2	78.3	54.5	25.2

Throughout these experiments the amount of bloom has been correlated with the quantity of fruit carried on the trees the preceding season. Correlation curves have been prepared in which are charted the number of fruits carried on each tree per 100-cm^2 cross section of trunk during the preceding season and the percentage of fruit-bud formation following. Distribution curves for the irrigated and the nonirrigated trees, showing average behavior, will then indicate whether fruit-bud formation was affected by the treatment. In this analysis of the data, trees are grouped as irrigated or nonirrigated, without regard to cultural treatments. Such distribution curves for the 1932 and 1933 bloom are shown for Oldenburg in figure 11 and for Rome Beauty in figure 12. The close paralleling of the irrigated and nonirrigated curves for Oldenburg indicate no difference in fruit-bud formation due to irrigation in the summers of 1931 and 1932. With the Rome Beauty there is indication each year of slightly greater fruit-bud formation on the irrigated trees which is believed to be due to the greater vigor of these trees rather than to a direct immediate effect of added water in influencing fruit buds to form.

In neither 1931 nor 1932 did the trees in the nonirrigated plots show evidence of lack of sufficient water until late July (about July 20 in 1931 and Aug. 1 in 1932). In 1930, on the other hand, the growth rate of fruit was sharply reduced in the nonirrigated trees after July 1. The results of Magness, Fletcher, and Aldrich (*10*) indicate that in the section in which these investigations were conducted fruit-bud formation can be influenced in but very few buds after July 15, or 75 days after full bloom. Thus the formation of fruit buds could be influenced by lack of moisture only in 1930, as shown by the bloom records taken in the spring of 1931.

The block of Delicious trees irrigated for the first time in 1932 carried a heavy crop of fruit, as did the nonirrigated trees. In this experiment neither group of trees bloomed in the spring of 1933. The crop in each case was so heavy that fruit-bud formation did not occur, and this result was not affected by the differential irrigation treatments. In that experiment, also, the trees were not affected by reduced moisture supply until the season during which fruit-bud formation could be affected had passed.

The results obtained to date relative to the effects of moisture supply on fruit-bud formation are not conclusive. The data for 1930 indicate that if there is a shortage of moisture during the

period in which fruit-bud formation can be affected, such shortage will tend to increase fruit-bud formation. In the Shenandoah-Cumberland Valley, fruit-bud formation in most varieties is not affected by experimental treatments given later than July 15, and the proportion of the buds that are affected after July 1 is small. Consequently it is apparently only early summer drought that might appreciably affect fruit-bud formation.

Following the very dry July and early August of 1930 there was a fairly heavy bloom of apples the next spring throughout the Shenandoah-Cumberland Valley as a whole. There was an excessively heavy bloom of peaches, in which fruit the formation of flower buds can be influenced through August. These general observations

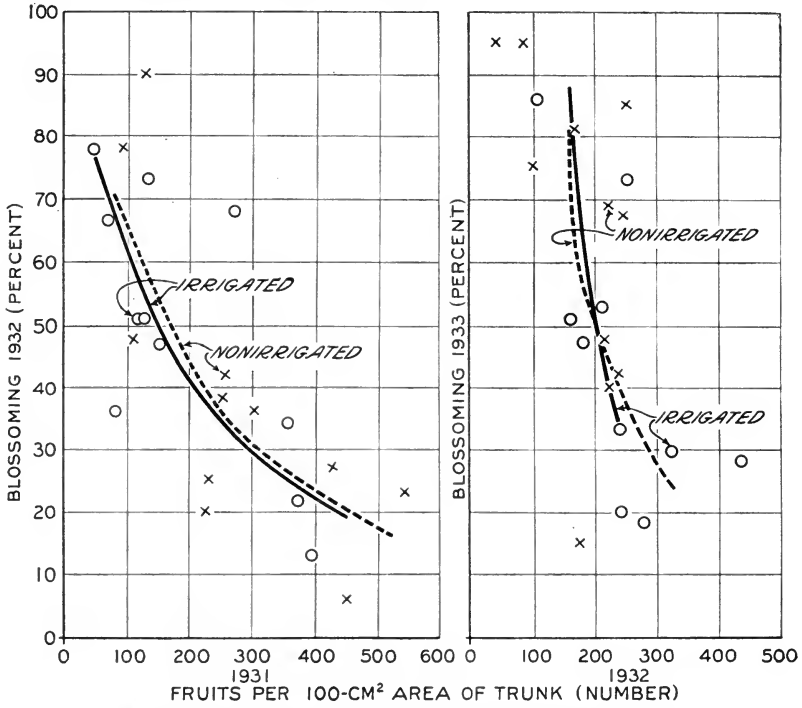

FIGURE 11.—Distribution curves for percentage of blossoming of Oldenburg apples, plotted against number of fruits borne per 100-cm² cross-sectional area of trunk during preceding season.

would tend to support the conclusion reported here that fruit-bud formation is increased under conditions of early summer moisture shortage. Similar results have been reported by Aldrich and Work (*2*) for pears in the Rogue River Valley of Oregon.

The most important factor in determining percentage of fruit-bud formation in these tests has been the number of fruits carried per tree in relation to the size of the tree or, more accurately, in relation to the foliage system of the tree. The maintenance of available moisture throughout the season through irrigation has not increased the tendency to form fruit buds. There is evidence from observations and limited experiments to indicate that periods of drought in early summer tend directly to increase the number of

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fruit buds formed. The increased vigor and larger foliage systems on trees irrigated regularly apparently may result in greater fruit-bud formation when the crop of fruit being borne is only moderate.

PHYSIOLOGICAL EFFECTS OF REDUCED MOISTURE SUPPLY ON APPLE TREES

Throughout the course of this work, investigations have been conducted to determine the effect of shortage of moisture on the nutrition or physiological functioning of the trees. Several reports have

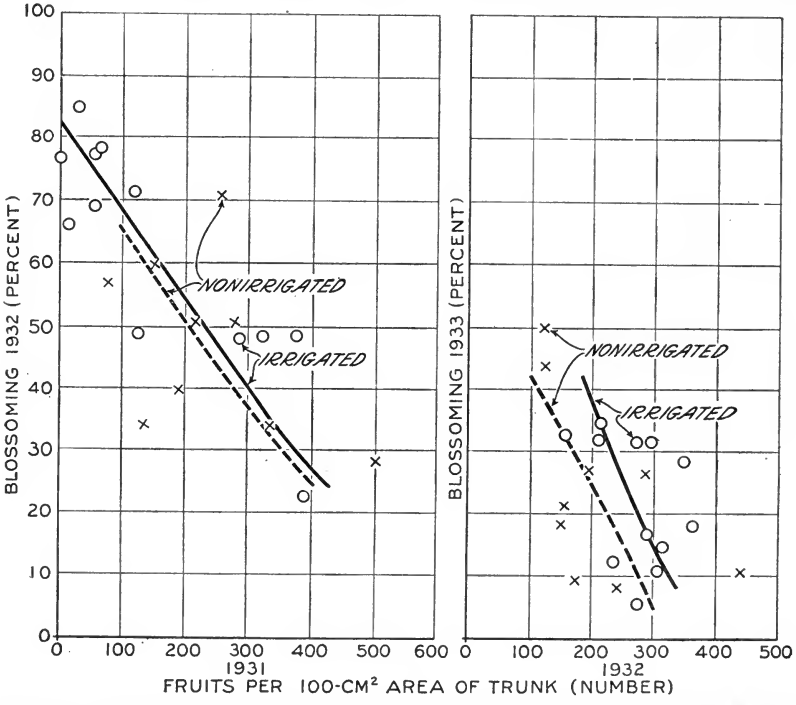

FIGURE 12.—Distribution curves for percentage of blossoming of Rome Beauty apples, plotted against number of fruits borne per 100-cm² cross-sectional area of trunk during preceding season.

been issued on various phases of these investigations, and detailed results previously published will not be included here. The following discussion summarizes the results obtained.

RELATION OF MOISTURE SUPPLY TO STOMATAL BEHAVIOR OF APPLES

Detailed results of a portion of these studies have been reported by Furr and Magness (*7*), and Furr and Degman (*6*). The stomata of apple leaves apparently are limited to the under surface. When moisture is available these stomata open in the morning, usually about the time the sun first strikes the leaves. With abundant moisture in the soil most of the stomata will open, the maximum number opening varying usually from 70 to 100 percent. The length of time these stomata remain open varies with the amount of available moisture in the soil and with the evaporating power of the air.

When the whole root zone is above the wilting percentage and humidity is high, most of the stomata will remain open throughout the day. On the other hand, with abundant soil moisture but with relatively high temperatures and low humidity, stomata may be completely closed before noon. With reduced moisture supply the period of stomatal opening under constant evaporating power of the air becomes correspondingly reduced. When the soil in most of the root zone of the trees reaches the wilting percentage, stomata may fail to open at all on the trees. With the soil at or near the wilting percentage but with the air nearly saturated during the early morning, the stomata will usually open for a short period but may be completely closed within an hour.

Previous results reported by Magness, Regeimbal, and Degman (*12*) indicate that the closing of the stomata in apple foliage is closely correlated with a decrease in moisture percentage in the leaf rather than with the accumulation of the products of photosynthesis. Apparently the stomata open under the stimulus of light, if the moisture content of the leaf is sufficiently high, and remain open until the moisture content is reduced to a certain point. The moisture content of the leaf rather than the accumulation of the products of photosynthesis seemed to be the important factor in determining the time of stomatal closing, under the conditions of these experiments.

EFFECT OF MOISTURE SUPPLY ON LEAF FUNCTION

It is extremely difficult, if not impossible, to determine accurately by leaf analyses the effect of reduced moisture supply and of earlier daily closing of the stomata on the quantity of carbohydrate materials formed in the leaf as a result of photosynthesis. These carbohydrates apparently move out of the apple leaf throughout the day as well as during the night. It seems logical to assume that this movement of carbohydrate materials from the leaf proceeds more rapidly when tissues are well supplied with moisture and when the water content of leaf and bark is high than when the water content in the conducting and storage tissues is reduced.

Investigations previously reported (*12*) have indicated that the content of both starch and sugar is slightly higher throughout the day in leaves of trees well supplied with moisture than in leaves of trees in which the moisture supply is so limited that the growth rate of the fruit is being measurably reduced. The greater photosynthetic activity of leaves well supplied with moisture is also indicated by the fact that trees and fruit supplied with an abundance of moisture throughout the season show a much higher total content of carbohydrates late in the summer than do similar fruit and trees that have suffered seriously for lack of water. These results indicate that one basic physiological effect of reduced moisture supply is reduced total carbohydrate formation in the leaves of the trees.

While it has not been demonstrated experimentally, it is believed that the carbon dioxide enters the leaf largely through the stomata and that the closing of the stomata under conditions of reduced moisture supply greatly diminishes the amount of carbon dioxide which enters the leaf. Since carbon dioxide and water are the two raw materials from which carbohydrates are manufactured in leaves, reduction of the amount of carbon dioxide that enters the leaf is

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probably the basic factor in the reduced photosynthetic activity. The moisture supply of the leaf is also reduced to an appreciable extent, in some tests being approximately 5 to 7 percent higher at the time of stomatal opening than at the time of stomatal closing. There is so much water present in the leaf, even at the time of stomatal closing, however, that it seems doubtful if deficiency of water is a direct factor in the reduced photosynthetic activity of the foliage under conditions of moderate water shortage.

A reduced period of stomatal opening is the first measurable effect of reduced moisture supply to the tree. Slight variations in the period during which the stomata remain open, due to reduced moisture supply, can be detected much earlier than changes in growth rate of the fruit can be measured. Results of these investigations indicate that the variation in time of stomatal opening is perhaps the most sensitive criterion of any change in the condition of the tree due to moisture variation. By following stomatal behavior throughout the day, variations in behavior can be detected when the moisture content of the whole root zone is apparently considerably above the wilting percentage, whereas at least a portion of the root zone on soils of medium or light texture apparently is usually at or near the wilting percentage before variations in the growth rate of fruit can be measured.

Rather limited data obtained to date (*12*) indicate that the leaves and bark are the organs of the tree which show greatest fluctuation in water supply throughout the day. Moisture content of the leaves may be reduced as much as 6 percent between sunrise and midafternoon, and the moisture content of the bark on branches less than 6 years of age may be reduced in approximately the same proportion. There is little daily fluctuation in the moisture content of the younger wood.

The moisture content of apple foliage did not continue to decrease after the stomata were closed except in leaves in a definitely wilted condition. When the trees were definitely wilted, moisture content of the foliage showed a slow decrease throughout the day even though the stomata were closed or were open for only a few minutes in the early morning.

EFFECT OF MOISTURE SUPPLY ON SUGAR AND STARCH CONTENT OF BARK, WOOD, AND FRUIT

On September 15, 1932, samples of bark, wood, and fruit from the irrigated and nonirrigated Delicious trees were taken. These trees, differentially handled for the first time during the growing season of 1932, had shown differences in fruit-growth rate beginning about July 8 (fig. 9). From that date through to time of sampling on September 15, or for a period of more than 2 months, decreased fruit-growth rate had occurred on the nonirrigated trees although at no time had they been in a definitely wilted condition. On September 15 the sugar content of the bark of the dry trees was from 14 to 19 percent higher than that of the bark of the irrigated trees. The sugar content of the bark was approximately five times as high as the sugar content of the wood.

On the same date the starch content of the bark of the irrigated trees was more than 30 percent higher than that of the nonirrigated

trees, with about the same differential in the starch content of the wood.

These results indicate that under conditions of reduced moisture supply to the trees the sugar content is relatively high while the starch content is reduced. Under conditions of abundant moisture supply the carbohydrate accumulates largely in the form of starch.

The percentage of starch in the wood of branches under 1 inch in diameter was practically the same as that of the bark from the same branches. Since the weight of wood in a large tree far exceeds the weight of bark, it is apparent that the total quantity of starch in these trees far exceeded the total quantity of sugar both in the irrigated and the nonirrigated trees. Since the starch content of the irrigated trees in both wood and bark averaged more than 30 percent higher than in the nonirrigated trees, it was apparent that the total amount of carbohydrate in these trees was much higher than in those that had suffered for moisture during the season.

The sugar content of the fruit averaged approximately 10 percent higher in that from nonirrigated trees which were suffering because of moisture shortage, while the starch content of the fruit from irrigated and nonirrigated trees was not consistently different. On this date, however, the average size of the fruit from irrigated trees was almost 50 percent greater than that from nonirrigated trees. Thus it is apparent that far more total carbohydrate had gone into the building of the fruit from irrigated than from nonirrigated trees. These data indicate that much more total carbohydrate had been built during the season in the irrigated than in the nonirrigated trees.

While more experimental data are needed on this point, results obtained indicate that the sugar content of bark and wood is higher in trees suffering for moisture, while the starch content and total carbohydrate is reduced under these conditions in proportion as leaf function is reduced. The fact that sugar concentration in trees growing under conditions of seriously reduced moisture supply is higher than in trees abundantly supplied with moisture may be of significance in the apparent increased fruit-bud formation which occurs under conditions of limited moisture supply if that reduction in moisture takes place during the period when fruit-bud formation can be influenced.

Analyses for total nitrogen in trees well supplied with moisture and those growing under conditions of moisture shortage have not shown a consistent difference in nitrogen content either on a wet-weight or dry-weight basis.

DISCUSSION

MOISTURE SUPPLY AND FUNCTIONING OF APPLE TREES

Results secured in these investigations indicate that apple trees are not measurably reduced in function, and growth rate of fruit is not measurably reduced so long as the moisture content of practically the whole root zone is above the wilting percentage. These results are in general agreement with the findings of Hendrickson and Veihmeyer (*8*, *9*), working with peaches and other fruits in California. In the present investigations, however, there was wide variation in root distribution so that the moisture in a portion of

the root zone might be reduced while much of the root system still had moisture available. Under these conditions, the degree of reduction in tree function seemed to depend on environmental conditions. During cool moist weather fruit growth was almost normal, even when the moisture in most of the root zone was reduced to the wilting percentage. On the other hand, during hot dry weather fruit-growth rate and the period of stomatal opening were markedly reduced if any considerable portion of the root zone reached the wilting point.

SOILS FOR ORCHARDS

Results secured in these investigations indicate that under conditions in the Middle Atlantic States, mature apple orchards, growing in soils 2 to 2½ feet deep and of good water-holding capacity, will exhaust their water to the extent that the fruit-growth rate is reduced within a period of 25 days during the summer. This holds true even if the soil is wet to the full field capacity at the start of the period. It rarely happens under natural rainfall conditions that a soil even of this depth is wet to full field capacity during the summer months. This would occur only if as much as 3 to 4 inches of rain had fallen and been absorbed by the soil within a very short period.

Under actual conditions as they existed during the 4 years, the growth rate of fruit on trees bearing a full crop generally was reduced following not more than 2 weeks of midsummer weather without rainfall. It is significant that during each of the past 4 years the growth rate of fruit on trees in such soils was reduced at some time during the growing season due to shortage of moisture, notwithstanding the fact that in 3 of the 4 years the total rainfall for the growing season was above average. In 2 of the 4 years the fruit hardly reached marketable size and was of poor quality because of lack of moisture.

These results indicate that under the conditions prevailing in the Middle Atlantic States and States westward having similar length of season and temperatures it is extremely hazardous to attempt to grow orchards on soils as shallow as 2 feet, even though they are retentive of moisture, of good fertility, and well drained. It would seem that the economic limit for orchard soils of good water-holding capacity, where orchards in that region are to be grown without irrigation, would be not less than 3 feet of good soil.

In regions farther north where the total length of the growing season is reduced and where the mean temperatures of the growing season are also lower, the hazard of moisture shortage decreases correspondingly. On the other hand, to the southward with even a longer growing season and higher seasonal temperatures, deeper soils and soils of better water-holding capacity are required to assure that the orchards will not suffer unduly from soil-moisture deficiencies. Except in the extreme north the planting of orchards on soils in which the root zone is limited, either by rock or by impervious and poorly drained subsoil, to less than 3 to 4 feet deep, should be considered as hazardous. Unless the soil is of good water-holding capacity with at least 10 to 12 percent of available moisture between

the field capacity and the wilting percentage, even more than 4 feet of depth would be required to assure fairly dependable moisture conditions.

THE VALUE OF MULCH IN MOISTURE CONSERVATION

Throughout these tests, plots heavily mulched with wheat straw with and without irrigation were compared with plots cultivated in the spring and then allowed to grow up to weeds with and without irrigation. A study of the results shown in figures 2 to 5 indicates that Rome Beauty apples were somewhat larger each season on the nonirrigated mulched plot than on the nonirrigated cultivated plot, and Oldenburg apples from the mulched plot were larger most of the years. It is not possible to say how much of this result can be attributed to difference in moisture and how much to increased organic matter. In these tests, trees in the nonirrigated mulched plot did not suffer for water quite so quickly as those in the cultivated plot owing to three factors: (1) The mulch was sufficiently heavy to keep down all weed growth to beyond the spread of the branches of the trees and transpiration from weeds did not occur as in the cultivated plot. (2) The mulch apparently reduced somewhat the surface evaporation of moisture from the soil. (3) The mulch completely prevented run-off of water during heavy rains and resulted in the soil taking up all moisture that fell. It is probable that under some orchard conditions, particularly on slopes or hilltops, the last effect is the most important of the three, since summer rains frequently come as heavy downpours of short duration. Under these conditions such a mulch insures the penetration of the water where it falls.

On the other hand, during periods of prolonged drought, nonirrigated trees growing under heavy mulch in soil only 2 to 2½ feet deep, suffered very severely from lack of moisture. The size of Rome Beauty fruit on the mulched nonirrigated trees was always smaller than that of the fruit from the irrigated trees either on the cultivated or mulched plots. When the trees growing under mulch exhaust the available water from the soil they suffer apparently as severely as nonmulched trees. While the condition of the Rome Beauty trees under mulch was fairly satisfactory on such shallow soils, they did not approach the condition of those where moisture was applied directly. There was less difference with Oldenburg where the fruit generally was harvested before a serious shortage of moisture occurred.

MOISTURE SUPPLY AND REGULAR BEARING

Irrigation under the conditions of these tests did not correct the tendency of trees to bear biennially. The York Imperial in block C remained biennial under irrigation. In 1932 the Delicious trees carrying a heavy crop failed to form fruit buds for the following year, either under irrigation or nonirrigation. Rome Beauty trees carrying a heavy crop in 1930 formed fewer fruit buds for the following year under irrigation than when the trees suffered for moisture during July. The direct effect of abundant moisture supply seems to be to decrease rather than to increase fruit-bud formation.

On the other hand, the trees that did not suffer for moisture during 4 years are more vigorous and thrifty than those that suffered

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from time to time. With these more vigorous trees it seems certain that regular production can be secured more easily than with trees in low vigor.

RELATION OF MOISTURE SUPPLY TO SIZE AND QUALITY OF FRUIT

In these tests the greatest benefit from having sufficient moisture throughout the growing season was in increasing the size of the fruit and, during seasons of drought, in greatly improving the color at harvest time. Since a market premium is usually paid for the larger sized and better colored fruits there were great gains in total marketable fruit and in market value per bushel under irrigation on the more shallow types of soil under the conditions of these tests. Yields of marketable fruit of late-maturing varieties were approximately doubled during the dry seasons and were appreciably increased in 3 of the 4 years during which these tests were run. These results apply only to the fairly shallow soils. With increasing depth of soil and increasing water-storage capacity at the beginning of the growing season, progressively decreasing benefits from irrigation could be expected under eastern conditions.

These investigations have emphasized particularly the desirability of selecting orchard soils where the root zone is deep and has good water-holding capacity. Where orchards are established on moderately shallow soils, irrigation will greatly benefit the yield and market quality of fruit during many seasons. With extremely shallow soils averaging not over a foot in depth under the conditions of these tests, irrigation to maintain sufficient moisture must be so frequent that the feasibility of attempting to operate such orchards either with or without irrigation is very doubtful.

WHEN IRRIGATION IS FEASIBLE UNDER EASTERN CONDITIONS

A practical question with many orchardists in the Eastern States is whether they should consider equipping their orchards for irrigation. Several factors must be considered in connection with this question.

There is enough good orchard land in the Eastern States which is sufficiently deep and retentive of moisture to produce the needed fruit crops of the country without irrigation. It seems doubtful if new orchards should be planted where irrigation is necessary unless unusual conditions of water availability prevail.

On the other hand, many orchards are now established on soils where moisture supply will frequently be a limiting factor in fruit production. With such orchards, if planted to good varieties and on good locations, irrigation is worthy of consideration if a dependable water supply is available. The main considerations should be the quantity of water available and the cost of distributing it in the orchard. Irrigation systems depending upon small streams for water supply are frequently unsatisfactory, since such streams may be dry or nearly dry during periods of extreme drought when irrigation is most needed. The expense of installing an irrigation system is warranted only in case the water supply is completely dependable.

QUANTITY OF WATER REQUIRED

In the Eastern States water requirement of the orchards is generally lower than under the arid conditions of the West, since with higher humidities the evaporating power of the air is generally lower. Also, it is only rarely that prolonged periods with a complete absence of light showers occur. In view of results obtained in these investigations it seems probable that 4 acre-inches of water per month would be required to maintain the trees at maximum functioning if no rainfall occurred. Such maximum usage would occur so seldom, however, that it seems doubtful if the orchardist would be justified in providing for the application of this quantity of water unless it could be done at fairly reasonable expense. On the other hand, 2 acre-inches of water, or approximately 54,000 gallons, would represent the minimum application per acre per month which might be considered as satisfactory in a supplementary irrigation system.

TYPES OF IRRIGATION

Various methods of applying irrigation water to orchards are in use in different parts of the United States. The method of delivering and handling the water on each individual orchard is a different problem and will not be discussed here. Throughout the course of these investigations the sprinkler method of application, where the water is pumped through pipes to sprinklers set on the tops of standpipes 12 to 14 feet high, has been used. Each of these standpipes, equipped with a sprinkler at the top, throws the water over an area of approximately 50 feet in diameter. Under this method the leaves and fruit of the trees are kept soaked for periods of 10 to 24 hours whenever an irrigation is given.

The sprinkler irrigation systems are satisfactory for orchards from the standpoint of distributing water on rough or broken land. On the other hand, wetting of the foliage and fruit has resulted in some increase in fungous diseases. The orchards in which these tests were conducted are clean and thoroughly sprayed, and the disease factor was not serious under these conditions. Although detailed records were not taken, it was evident that there was a slight increase in scab infection in the plots irrigated with sprinklers. These results are in line with those obtained in Washington (*13*).

Fletcher (*5*) reporting in part on the same tests that are reported here, found apparently somewhat poorer color on the sprinkler-irrigated plots than on similar plots irrigated in furrows in which the fruit and foliage were not wet. These results also are similar to those obtained in Washington.

These factors indicate the desirability, particularly in the Eastern States, of applying the water directly on the ground, where possible, rather than through sprinklers. Furrow irrigation is very satisfactory in orchards that are not too steep and in which the soil is not too open or porous. In orchards too steep or with the soil too open for furrow irrigation, application of water through such devices as perforated hose is fairly satisfactory. The sprinkler system is very satisfactory from the standpoint of good distribution and

ease of handling, but it requires a fairly expensive installation to distribute the water. The best method of handling the water on individual orchards can be determined only by a thorough study of the particular condition in each orchard.

WHEN WATER SHOULD BE APPLIED

One of the most difficult problems in connection with irrigation is to determine when water should be applied in the orchard. Too frequent or too heavy irrigations may result in water-logging of the soil, particularly if it is poorly drained, as well as in unnecessary expense in the application of the water. If irrigation is delayed too long and growth rate of fruit is seriously retarded as a result of lack of moisture, fruit size at the end of the season will be reduced in proportion.

The keeping of accurate records of rainfall is valuable in determining when irrigation should be applied under eastern conditions, where summer rainfall is generally rather frequent. The experienced grower can judge fairly well how long the soil in various parts of the orchard will carry the trees following a thorough irrigation, if he considers the amount of rainfall that has occurred.

A very valuable index is the wilting of relatively shallow-growing plants in the orchard. When shallow-growing vegetation becomes wilted, and particularly if it remains so during the cooler parts of the day, it is an indication that the soil in the root zone of those plants is at or near the wilting percentage. After that condition is reached it will not be long until the trees also begin to suffer unless moisture is applied.

The present studies, as well as others (*11*) reported from Washington, indicate that under ideal conditions the late varieties of apples grow at an approximately steady rate on a volume basis from late June through until near harvest time. One of the best indexes as to when the trees are suffering for water is the reduction in the growth rate of fruit. This can be followed rather accurately by tagging certain fruits and measuring their circumferences at intervals and plotting their increase in size on a volume basis. While this practice would be somewhat unusual in commercial orchard management, it could be done with a limited amount of time and might be very helpful to the orchardist who is starting in to practice irrigation, as it gives an excellent index as to when his particular trees need additional moisture. If the same apples are measured from week to week, or preferably at least twice a week, measurements on a large number of individual apples are not needed to determine the growth condition of the fruit as a whole.

Orchards on deep soils of poor water-holding capacity, or on shallow soils even with excellent water-holding capacity, will suffer greatly because of moisture shortage under such rainfall conditions as have prevailed during many years in the eastern part of the United States. Moisture-conservation measures such as mulching to prevent run-off and to keep down competing vegetative growth, or cultivation, which eliminates the competition of other plants, are helpful in maintaining orchards under these conditions. Under severe drought conditions, however, the actual application of water through irrigation is the only means of obtaining optimum fruit

growth and quality. Apple trees carrying little fruit will stand drought conditions well, but with heavy crops on the trees the immediate as well as later effects on the tree are serious.

SUMMARY

Investigations have been conducted through four growing seasons, 1930–33, inclusive, to determine the soil-moisture conditions and tree response in irrigated and nonirrigated plots in apple orchards in western Maryland.

During 3 of the 4 seasons, total rainfall from May 1 to October 31 was above normal, yet in each season apple trees in rather shallow shale soil showed reduced fruit-growth rate due to moisture shortage at some time during the season.

The growth of apples measured on a volume basis proceeds at very nearly a uniform rate from a period some 6 to 8 weeks following bloom until near harvest time, if all conditions are favorable.

The growth rate of the fruit of trees growing in moderate textured silt loam or silt clay soils is generally not measurably reduced because of moisture shortage until at least the driest parts of the root zone approach the wilting percentage.

When ample moisture is restored following a period of reduced growth rate due to moisture shortage, growth of fruit is resumed at apparently normal rate, provided the drought has not been so severe as to cause serious loss of foliage.

The size of the fruit at the end of the season will be reduced in proportion to the length and duration of the drought. Following even a short period of reduced growth rate, the ultimate size of the fruit will be reduced accordingly.

During the 4 years of these tests the yield of Rome Beauty was increased more than 50 percent because of increased size of fruit, due to irrigation. Oldenburg, on the other hand, when harvested in late July, showed little increase in yield or size of fruit due to irrigation.

The color of the fruit is dull and lifeless when the ripening season occurs while trees are suffering from lack of moisture. Moderate available moisture during the late-growing season has given maximum color, both in brightness and in area. Excessive moisture tended to reduce the amount of color.

When moisture shortage occurs not later than early July, fruit-bud formation appears to be increased. Water shortage during the period from late July until fall apparently has no effect on fruit-bud formation.

The first measurable effect of reduced moisture supply on the functioning of apple trees is an earlier closing of the stomata. This occurs prior to a reduction in the growth rate of fruit.

Leaf function apparently is reduced under conditions of insufficient moisture supply, and the total carbohydrate materials in the trees are less than under conditions of ample moisture.

The sugar content of bark and wood of the trees is markedly higher following a period of serious moisture shortage than it is in trees well supplied with moisture. The starch content is much lower in the trees suffering from deficient moisture.

The effects of soil-management practices on soil moisture and the value of irrigation under eastern orchard conditions are discussed.

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UNITED STATES DEPARTMENT OF AGRICULTURE
WASHINGTON, D. C.

EXPLOSIBILITY OF AGRICULTURAL AND OTHER DUSTS AS INDICATED BY MAXIMUM PRESSURE AND RATES OF PRESSURE RISE

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INTRODUCTION

Three hundred and eighty dust explosions occurred in industrial establishments in the United States from 1916 to 1934, inclusive, the period for which records are available. In these explosions 308 persons were killed, and 680 were injured. The property losses amounted to $34,212,629, an average loss of about $90,000 for each explosion. These explosions have occurred in practically all the grain-handling industries, such as elevators, flour and feed mills, and starch factories; in many industries associated with agricultural operations such as sugar refining, preparing powdered milk and other food products, insecticides, wood flour, cottonseed meal, soap powder, and paper dust; and in many others using agricultural products.

Under favorable conditions a dust explosion can occur in any industrial plant or manufacturing establishment where combustible dust is created. Approximately 28,000 industrial plants in the United States are subject to this hazard. These plants normally employ approximately 1,325,000 persons and manufacture products having an annual value of more than 10 billion dollars.

A dust explosion consists essentially of pressure produced by the rapid burning of dust suspended in air. The pressure produced by the rapid burning of the dust cloud and the rate of pressure rise are responsible for the damage caused by the explosion. The rate of burning of the dust cloud is affected by the size, the ease of ignition, and the heat of combustion of the dust particles, and also by the concentration [1] of the dust in air.

It is not the purpose of this bulletin to explain the mechanism of a dust-cloud explosion, but it should be emphasized that at least 80

[1] The word "concentration" as used in this bulletin refers to the weight of dust per given volume of air.

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percent of the pressure is due to the expansion of the gaseous products of combustion and the residual air brought about by the heat from the rapid combustion. In some cases the rest of the pressure is the result of an increase in volume of the gases, the increase depending upon the kind of dust that is burned. The following chemical equations show this variation:

1. $C+O_2+4N_2 \rightarrow CO_2+4N_2$
2. $4Al+3O_2+12N_2 \rightarrow 2Al_2O_3+12N_2$
3. $C_{12}H_{22}O_{11}+12O_2+48N_2 \rightarrow 12CO_2+11H_2O+48N_2$

The first equation illustrates the chemical reaction of carbon burning in air. Air is represented by 1 volume of oxygen and 4 volumes of nitrogen. After combustion there are 1 volume of carbon dioxide and 4 volumes of nitrogen; therefore the total volume of the gas before and after combustion is the same. Since the volumes are the same any pressure produced is due entirely to the heat generated by the reaction.

The second equation shows the reaction between aluminum and air. Before burning there are 15 volumes of gas and after burning there are only 12, the Al_2O_3 being a solid that occupies a negligible space as compared with the gases. Therefore there is less gas after the burning than before. This would cause a decrease in pressure if it were not for the heat liberated by the reaction.

The third equation shows the reaction when sugar is burned in air. Sixty volumes of air are required to burn the sugar to 71 volumes of carbon dioxide, water vapor, and nitrogen. This is an increase in volume of about 18 percent.[2] These equations show that little of the pressure produced by a dust explosion is due to an increase in volume of the gases after combustion. Most of the pressure is due to the heat liberated by the combustion, which in turn expands the gases.

These equations represent the complete combustion of the materials in the theoretical amount of air required. It is doubtful if this condition has ever occurred during a dust explosion. Laboratory tests show that in a dust explosion all the oxygen is not consumed, which means that the ratio of the volume of gases after combustion to the volume before is less than that shown by equation 3, which is representative of most organic dusts.

The discussion above does not refer to explosives such as dynamite and smokeless powder. These materials do not depend on the oxygen in the air for combustion, but they produce large volumes of gases on detonation, and the heat generated expands them further so that very high pressures are attained.

METHODS FOR DETERMINING EXPLOSIBILITY

A number of methods for the determination of the explosibility [3] of dust are described in the literature (*2*, *4*).[4] Practically all these methods can be classified under two general types, namely, open and closed systems.

The open system usually consists of a gallery, and as its name implies, it has at least one opening through which the explosion is vented without damage to the gallery. In this system, the explosi-

[2] During a dust explosion the water formed as a product of combustion exists in the vapor phase because of the relatively high temperature produced by the combustion.
[3] In this bulletin the terms "explosibility" and "flammability" are used synonymously.
[4] Italic numbers in parentheses refer to Literature Cited, p. 24.

bility of a dust is determined by the length of flame produced when the dust cloud in the gallery is ignited or by the quantity of inert dust required to prevent or limit the propagation of flame.

The closed system consists of a gastight bomb in which a dust cloud is produced and ignited, and a suitable indicator on which the pressure from the resulting explosion is recorded. The maximum pressure developed during the explosion has been considered the criterion in measuring the explosibility of the dust.

The Bureau of Chemistry and Soils uses the closed system for laboratory research and the open system for large-scale tests. A description of the closed-type apparatus used in the investigation reported in this bulletin is given on page 4. In addition to the maximum pressure developed, the maximum and average rates of pressure rise are given as criteria of explosibility. The reasons for including the maximum and average rates of pressure rise in the evaluation of explosibility are dealt with more fully under the heading, Discussion of Results.

Data on the maximum pressures developed in the explosion of various dusts under laboratory conditions are rather extensive, but there is comparatively little published information in regard to the rate of pressure rise during such explosions. So far as the authors know, such information is limited to coal and coke dusts (*3*). Moreover, the source of ignition used for much of the previous work was at a considerably lower temperature than that used in the present investigation; also other experimental conditions were different, so that the figures in this bulletin are not directly comparable to those obtained in previous work, even in regard to maximum pressures. A good summary of figures on maximum pressures of various dusts as known at that time is given by Price and Brown (*4, pp. 26–28*).

A large part of the work on the explosibility of dust in air previously reported has been conducted at one concentration (*4*), but to obtain complete data on the explosibility of a dust, tests must be made throughout its explosive range, because the pressure developed on explosion and the rates of pressure rise vary with the concentration of dust in air. In the investigation reported here tests were made at two concentrations, namely, 100 milligrams and 500 milligrams per liter, which is equivalent to 100 ounces and 500 ounces per 1,000 cubic feet, respectively.

Maximum pressure, average rate of pressure rise, and maximum rate of pressure rise, at both concentrations have been assumed to be of equal value as criteria of explosion hazard. This is of necessity rather arbitrary, as in an actual dust explosion these variables are affected by many factors, such as concentration, size and distribution of dust particles, size and shape of apparatus or structure in which the explosion occurs, atmospheric humidity, and size and temperature of the ignition source. These factors may alter the maximum pressure and rate of pressure rise in various ways, as is shown herein in the case of concentration. Hence the ratings given apply only to the conditions under which these tests were made. All the tests, however, are comparable.

APPARATUS

The apparatus used in this work consists essentially of two parts, the bomb in which the explosion occurs and the British coal-dust

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recording manometer (*5, p. 151*), which gives a continuous record of the pressure within the bomb during the test.

In figure 1 the 1,417-cubic centimeter bronze bomb (*a*) is seen removed from its seat, exposing the hemispherical dust-sample cup (*b*); the ignition electrodes (*c*) extending downward from the yoke; and outlet tubing (*d*) leading to the recording manometer (*e*). A revolving drum (*f*) on the manometer carries a stylograph chart. The pressure from an explosion in the bomb is transmitted through the tube (*d*) to a piston in the manometer. The piston actuates a calibrated flat steel spring, on which is attached a stylus. The stylus in turn makes a permanent record of the change in pressure on the chart carried by

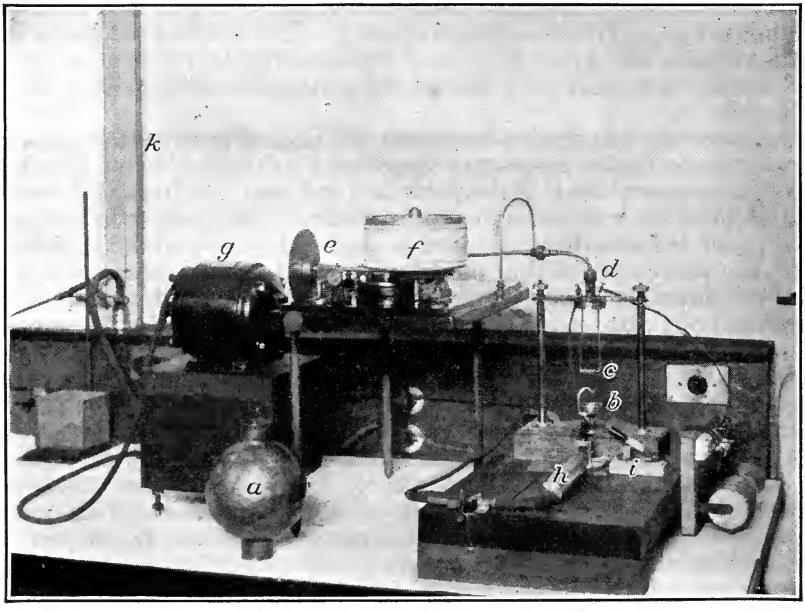

FIGURE 1.—Apparatus for determining explosibility of dusts.

the manometer drum (*f*). The manometer drum is driven through suitable gears by a synchronous motor (*g*) so that a horizontal displacement of 1 inch is equivalent to 0.1 second. Since it is possible to read displacements to 0.01 inch, time can thus be determined to 0.001 second.

Previous work (*6*) in this Bureau has shown that the most satisfactory way to obtain a uniform dust cloud is to blow a jet of air into a hemispherical cup which holds the dust. The hemispherical dust cup (*b*) is 1.6 centimeters in radius and has a polished inner surface. At a point on the center line, 1.5 centimeters above the level of the top, air for dispersing the dust is discharged from a brass tube of 3 millimeters inside diameter. In front of the sample cup is a brass cylinder (*h*) of 100 cubic centimeter capacity, in which air for dispersing the dust is stored under pressure equivalent to 20 to 40 centimeters of mercury, depending upon the concentration and dispersability of the dust. This small storage tank is connected with the air-jet tube by a reinforced rubber tube capable of withstanding pressure up to

about 100 pounds per square inch. A clamp actuated by a trigger is placed on the rubber tube between the air reservoir and the air jet. A small helical spring opens the clamp, and hence the rubber tube, almost instantaneously upon release of the trigger. Connected to this trigger by a link is an electrical switch (*i*) which controls the firing within the bomb. Upon closing the electrical switch for ignition, the valve or clamp controlling the air for the dispersion of the dust is opened, causing the dust cloud to be formed and ignited in close sequence. The interval between these two events is short and depends in part upon the length of the link connecting the valve and the switch. In the background, a mercury manometer (*k*) indicates the air pressure within the storage cylinder for dispersion of the dust. Before a test is made, this manometer is cut off from the rest of the system by a glass stopcock shown in front of the storage cylinder.

The dust cloud is ignited by a 0.1-gram pellet (*3, p. 75*), placed between the electrodes at *c*. This pellet, 4 millimeters in diameter and 2 millimeters thick, is composed of equimolecular proportions of powdered magnesium and barium peroxide intimately mixed and compressed under a load of 5,000 pounds with a hydraulic press. After ignition of the pellet, magnesium oxide and barium oxide remain as solid products of combustion having the appearance of a drop of slag between the electrodes. As chemically equivalent quantities of material interact, one being oxidized and the other reduced, no oxygen or other gas is given up to the air, or removed from it, and hence the dust cloud is neither enriched by nor depleted of oxygen. Combustion thus takes place in a normal atmosphere.

The pellet is held in place by the slightly compressive action between the electrodes (*c*) which project downward to the center of the bomb. Two wires, just above the yoke, lead from the source of a 110-volt alternating current and the switch (*i*), and make electrical connection with the upper terminals of the electrodes through a suitable resistance. When the electrical circuit is closed, a current flows through the pellet, causing its ignition by the heat generated within it. This ignition source, which is of very short duration, has a temperature calculated to be about 1,800° C. The pressure in the bomb resulting from the burning of the pellet and from the air used to throw the dust into suspension is about 0.5 pound per square inch. The data presented in the tables are corrected for this 0.5-pound-per-square-inch pressure.

PROCEDURE

In making an explosibility test, the dust is weighed and placed uniformly in the sample cup (*b*) and the bomb is placed on its base. In this position the cup is at the bottom of the spherical portion within the bomb. The lower tubulure of the bomb surrounds the cup and rests on its rubber-gasket seat. The head is clamped down and held in place by a yoke, the outer ends of which are maintained in place by thumb-screws. When the head is in place, its rubber gasket fits tight on the upper tubulure of the bomb and the electrodes with the pellet between them extend to the center of the bomb. The tube from the bomb to the recording manometer is joined by a pipe union near the head of the bomb. The electrical switch (*i*) is nearly but not entirely closed. The air valve near it is closed, and the link is inserted between the two, connecting them mechanically.

Air is admitted to the storage cylinder (*h*) until the mercury manometer (*k*) records the proper pressure, then the glass stopcock between them is closed. The synchronous motor is started, and the test is ready to be made. When switch (*i*) is closed the air jet blows the dust into suspension from the cup, the pellet flashes, the dust ignites, the pressure change leaves its record as a vertical displacement on the chart on the manometer drum, and the test is completed.

Typical time-pressure curves are shown in figure 2.

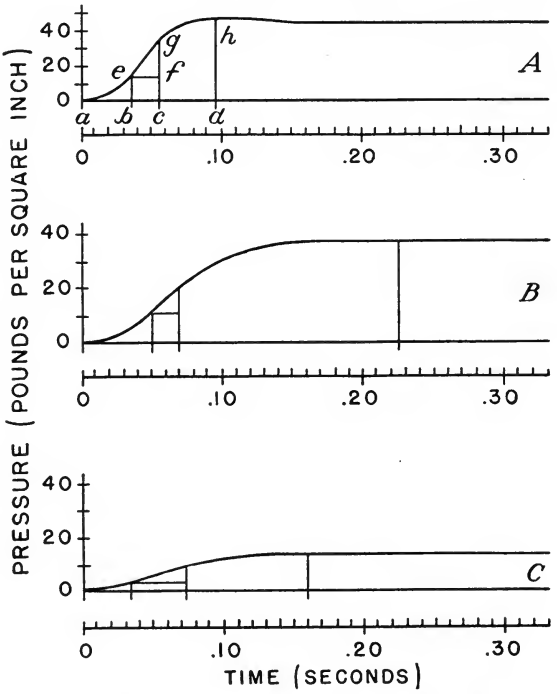

FIGURE 2.—Time-pressure curves for (*A*) alkali starch, 500 milligrams per liter, (*B*) yellow corn meal, 500 milligrams per liter, and (*C*) yellow corn meal, 100 milligrams per liter.

A 30-pound spring was used for pressures not to exceed about 35 pounds per square inch; for higher pressures this was replaced by a 50-pound spring. During the course of this work, each of these springs had been calibrated against a standard gage and, for some points, against a mercury column. On the alkali starch curve, the vertical distance *dh* indicates the maximum pressure. The horizontal distance *ad* represents the time required to attain the maximum pressure. The average rate of pressure rise is therefore the maximum pressure divided by the time or, as shown in figure 2, $\frac{dh}{ad}$. The steepest portion of each curve is then selected for a determination of maximum rate of pressure rise. The portion *eg* is the steepest portion of the alkali-starch curve. *fg* indicates the pressure difference over this interval, and *ef* indicates the time which elapses during this pressure increase. The maximum rate of pressure rise is therefore simply the pressure divided by time for this part of the curve or, as shown in the diagram, $\frac{fg}{ef}$.

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One hundred and thirty-three materials were tested. With the exception of aluminum and bagasse paper, they were all passed through a 200-mesh screen. In most cases the greater portion of the material passed through this screen. In some instances, however, such as the long-fibered woods, only a relatively small portion of the original sample passed through the 200-mesh screen. With the exception of the metal dusts, all the materials were dried, most of them for 4 hours in vacuo at 70° C. However, owing to their oily nature or to a low melting point, or for other reasons, some of the dusts were dried in a vacuum desiccator over concentrated sulphuric acid for 3 days.

In testing the metals, precautions were taken to obtain fresh, unoxidized material; in some cases the materials were taken from previously unopened bottles. The zinc, as is the case with most "zinc powder", contained some zinc oxide. The analysis as given on the bottle follows: Zn (reducing action), about 95 percent; Pb, 0.11 percent; Fe, 0.008 percent; Cd, 0.004 percent; As, —0.0001 percent.

According to the label, the sample of dry lime-sulphur had the following composition: Active ingredients, 85 percent, consisting of calcium polysulphide, 70 percent; calcium thiosulphate, 5 percent; sulphur, 10 percent; inert ingredients, 15 percent.

The organic materials were obtained from reliable sources and for the most part were fresh; some of the materials had been in this Bureau for a number of years in tightly closed jars and appeared to be in good condition. Materials that had to be dried were dried shortly before testing, and between the drying and weighing of charges were kept in tightly closed weighing bottles in a desiccator over calcium chloride. Immediately after being weighed, the charges were transferred to the cup, the bomb was clamped down, and the dusts were exploded as indicated previously.

As the testing was done over a number of months, the atmospheric humidity and temperature varied widely; the relative humidity ranged from 21 to 94 percent and the temperature from 68° to 91° F. There were no facilities for control of either of these factors. However, the temperature differences would have but a minor effect, and it is believed that the humidity differences caused no important variations in view of the short time that any dust was exposed to the atmosphere before exploding. The two concentrations, 100 milligrams per liter and 500 milligrams per liter, were chosen with the thought that they would be different enough to give a fair picture of behavior at different concentrations. Some materials were tested only at the lower concentration, in some cases owing to a lack of 200-mesh material, in others because the cup was not large enough to hold the material at the higher concentration. Alkali starch and wheat smut no. 2 were run at only one concentration because other very similar materials had been run at both concentrations, and the additional information was deemed superfluous. Aluminum was used as a kind of check through the whole series to determine whether substantially the same results were being obtained from time to time; this accounts for the large number of tests with aluminum. Generally three tests were made for each material at each concentration. In a few cases, usually where the pressures were very low, only two tests were made for each concentration. When the agreement between individual tests was

poor, four or more were run in order to obtain a more significant average.

DISCUSSION OF RESULTS

Wheeler (7) has shown that in gaseous combustions in spherical bombs the flame reaches the wall of the bomb at the same instant that maximum pressure is attained. To produce this condition, it is necessary that the flame reach all the surface of the bomb at the same instant, and that it travel so rapidly that convection currents are not set up. The average speed of the flame in the bomb during gaseous combustions is, therefore, the radius of the bomb divided by the time from the initiation of the combustion until maximum pressure is attained.

In most dust explosions the flame speed is not so high as in most gas explosions; therefore some convection currents may be created. It is also highly probable that the flame front does not reach all the surface of the bomb at the same instant. It is believed, however, that under the conditions of test which have been described, the time from the initiation of the explosion until maximum pressure is reached is a fairly accurate measure of the average flame speed. Since all these tests were made under the same conditions, the values obtained should be fairly comparable.

The average rate of pressure rise is a function of the maximum pressure produced and the length of time from the initiation of the explosion until maximum pressure is reached. Since this length of time is a measure of the average speed of the flame, it is apparent that the average rate of pressure rise is derived from two very important factors in the mechanism of an explosion.

No building can withstand a dust explosion if the pressure produced within the building is comparable with that produced by an explosive dust in a closed system. In the study of the damage done by dust explosions, it has frequently been found that the windows were blown out, while the walls were not damaged. It seems logical to assume that in these cases the pressure within the building built up relatively slowly, and when the windows were blown out, sufficient openings were provided to prevent a rapid rate of pressure rise, which in turn prevented additional damage to the structure. Other investigations have shown that the very rapid rate of pressure rise is responsible for the destruction of buildings. As an example, a rather unusual case can be cited where a solid 13-inch brick wall was blown out, while a window located directly above it remained intact. If the rate of pressure rise had been lower, it is quite possible that the window would have been blown out and the wall left undamaged. Apparently the rapid rate of pressure rise which develops during an explosive reaction and which may be called the dynamic load is chiefly responsible for the structural damage caused by a dust explosion.

The maximum rate of pressure rise is the maximum rate that the dynamic load develops during an explosive reaction. This dynamic load, if not released by vents or openings, will destroy the structure. Brown and Hanson (1) have shown graphically the relation between the maximum pressure developed by the burning of clouds of wheat elevator dust and cornstarch in a certain type of structure and the vent area required to release this pressure. The maximum pressure obtained with a given vent area is always higher for cornstarch than

for wheat-elevator dust. In the experiments reported in this bulletin (closed system) the maximum pressures were about the same, but the average and maximum rates of pressure rise were higher for cornstarch than for wheat-elevator dust. This means that the dynamic load increases more rapidly during the burning of cornstarch than it does during the burning of grain dust. It seems highly desirable, therefore, to include both the average and maximum rates of pressure rise in the evaluation of the relative flammability or explosibility of a dust. Before these data can be used in determining venting requirements, however, it will be necessary to determine with large-scale equipment the relation between the maximum pressure and the vent area for other dusts.

The data derived from the time-pressure curves are presented in table 1. The materials are arranged by sources, reading generally from the highest to the lowest values for maximum pressure at 100 milligrams per liter. An attempt was made, however, to keep closely related materials together in the tables, regardless of their exact position as regards maximum pressure at 100 milligrams per liter. In the following discussion the number in parenthesis which follows the name of a material is the serial number of the material in table 1.

TABLE 1.—*Time-pressure data for various dusts*

FOOD PRODUCTS AND BYPRODUCTS

Serial no.	Material	Concentration [1]	Tests	Maximum pressure	Average rate of pressure rise	Maximum rate of pressure rise
		Mg per liter	*Number*	*Lb. per sq. in.*	*Lb. per sq. in. per sec.*	*Lb. per sq. in. per sec.*
1	Cellulose	100	3	27	284	814
		500	3	46	414	1,111
2	Rice starch	100	3	26	233	546
		500	3	41	218	852
3	Potato starch	100	4	18	138	361
		500	3	38	257	722
4	Wheat starch	100	4	20	134	326
		500	3	40	290	825
5	Hard winter wheat flour	100	3	21	127	363
		500	3	40	219	614
6	Soft winter wheat flour	100	3	21	161	355
		500	3	37	204	509
7	Spring wheat flour	100	8	20	121	330
		500	3	34	177	567
8	Whole-wheat flour	100	3	17	103	224
		500	7	33	161	490
9	Bran	100	3	4	23	[2] (23)
		500	4	30	121	288
10	Wheat-elevator dust	100	3	20	154	311
		500	3	46	329	720
11	Cracker meal	100	3	20	108	272
		500	3	41	240	481
12	Wheat smut (no. 1)	100	3	21	111	328
		500	3	40	169	567
13	Wheat smut (no. 2)	100	3	22	111	466
		500	[3]	[3]	[3]	[3]
14	Cornstarch	100	3	23	166	577
		500	3	43	360	863
15	Alkali starch	100	[3]	[3]	[3]	[3]
		500	3	47	483	1,076
16	Corn-elevator dust	100	3	23	237	570
		500	3	43	299	865

[1] The concentration of dust in air as reported in milligrams per liter is equivalent to ounces of dust per 1,000 cubic feet.

[2] Maximum rate of pressure rise was not determined. The value for average rate is inserted as the maximum rate was equal to this at least.

[3] Test made at one concentration only.

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TABLE 1.—*Time-pressure data for various dusts*—Continued

FOOD PRODUCTS AND BYPRODUCTS—Continued

Serial no.	Material	Concentration	Tests	Maximum pressure	Average rate of pressure rise	Maximum rate of pressure rise
		Mg per liter	*Number*	*Lb. per sq. in.*	*Lb. per sq. in. per sec.*	*Lb. per sq. in. per sec.*
17	Gluten meal	100	3	19	104	210
		500	4	36	169	350
18	Yellow corn meal	100	3	13	77	121
		500	3	36	165	411
19	Cornstalk flour	100	3	22	165	351
		500	3	42	301	696
20	Barley flour	100	3	19	119	242
		500	3	35	271	739
21	Barley-elevator dust	100	3	14	76	175
		500	3	37	127	404
22	Malt	100	3	22	177	403
		500	3	36	179	541
23	Rye flour	100	3	20	132	465
		500	3	36	295	722
24	Tapioca flour	100	3	20	210	529
		500	3	42	278	715
25	Buckwheat flour	100	3	16	104	174
		500	3	36	185	547
26	Soybean flour	100	4	15	101	260
		500	4	26	87	251
27	Peanut-hull flour	100	3	14	65	119
		500	4	29	118	356
28	Oat dust from dry kiln	100	3	23	216	558
		500	3	43	329	841
29	Oat hulls	100	3	12	62	132
		500	3	35	121	254
30	Oat-elevator dust	100	3	20	135	383
		500	4	38	139	601
31	Kafir corn	100	8	20	144	345
		500	3	41	301	831
32	Alfalfa	100	3	16	93	172
		500	5	32	117	289
33	Sucrose	100	4	22	138	362
		500	3	31	167	526
34	Levulose	100	4	20	141	292
		500	3	45	316	665
35	Dextrose	100	3	19	126	278
		500	3	43	205	398
36	Lactose	100	3	12	89	177
		500	4	22	82	168
37	Dextrin	100	3	13	105	469
		500	3	24	204	1,400
38	Pectin	100	3	17	116	198
		500	4	33	186	443
39	Agar	100	3	23	140	339
		500	2	43	216	446
40	Gelatin	100	3	28	214	470
		500	[3]	[3]	[3]	[3]
41	Egg albumen	100	6	13	54	84
		500	7	30	134	280
42	Copra meal	100	3	13	75	151
		500	3	21	87	188
43	Linseed meal	100	3	12	65	141
		500	7	25	99	216
44	Cottonseed meal	100	8	7	32	58
		500	6	22	83	145
45	Cocoa	100	4	5	33	45
		500	3	23	79	218
46	Powdered skim milk [4]	100	4	26	209	465
		500	3	41	210	423
47	Powdered buttermilk	100	4	20	118	226
		500	7	42	176	320
48	Powdered milk [5]	100	3	4	19	25
		500	[3]	[3]	[3]	[3]
49	Powdered whole milk [6]	100	4	17	91	219
		500	4	31	142	441
50	Casein	100	3	23	167	395
		500	6	39	239	480

[3] Test made at one concentration only.
[4] Contained practically no butterfat.
[5] Contained 16 percent of butterfat.
[6] Contained 28.20 percent of butterfat.

TABLE 1.—*Time-pressure data for various dusts*—Continued

SPICES, DRUGS, INSECTICIDES, ETC.

Serial no.	Material	Concentration	Tests	Maximum pressure	Average rate of pressure rise	Maximum rate of pressure rise
		Mg per liter	*Number*	*Lb. per sq. in.*	*Lb. per sq. in. per sec.*	*Lb per sq. in. per sec.*
51	Cinnamon	100	4	25	312	795
		500	8	43	269	622
52	Sage	100	3	24	176	433
		500	3	38	192	434
53	Black pepper	100	4	23	212	438
		500	4	43	233	462
54	Paprika	100	3	23	134	297
		500	3	40	186	373
55	Nutmeg	100	4	23	159	343
		500	4	42	228	606
56	Oriental licorice root	100	3	18	144	277
		500	3	31	128	374
57	Spanish licorice extract	100	3	20	119	220
		500	3	45	206	476
58	Cloves	100	3	17	123	248
		500	3	30	107	381
59	Allspice	100	7	16	99	207
		500	3	28	114	415
60	Cardamom seed	100	3	16	79	206
		500	6	37	235	552
61	Ginger	100	7	10	50	90
		500	3	34	136	341
62	Lycopodium	100	4	33	345	817
		500	3	36	163	453
63	Cinchona bark	100	4	25	239	627
		500	3	35	173	443
64	Squill	100	3	23	218	481
		500	3	41	247	703
65	Hellebore	100	4	21	126	294
		500	4	35	174	567
66	Gentian root	100	7	21	169	413
		500	3	34	113	411
67	Blood root	100	3	19	141	321
		500	4	37	185	424
68	Cascara sagrada	100	3	19	184	398
		500	3	43	249	698
69	Buckthorn bark	100	3	19	155	359
		500	3	39	129	540
70	Pyrethrum	100	3	19	122	448
		500	3	36	127	486
71	Belladonna leaves	100	4	13	67	118
		500	4	22	82	136
72	Althea root	100	4	12	63	125
		500	6	26	109	254
73	Tea fluff	100	3	21	147	431
		500	8	35	163	487
74	Smoking tobacco	100	4	7	36	[2] (36)
		500	4	23	95	150
75	Tobacco-stem dust	100	2	1	[7]	[7]
		500	2	1	[7]	[7]

WOOD, PAPER, TANNING MATERIALS, ETC.

76	Redwood	100	3	25	256	528
		500	3	40	256	666
77	Redwood bark	100	4	22	201	413
		500	7	38	250	557
78	Balsa	100	3	24	172	422
		500	[3]	[3]	[3]	[3]
79	White pine	100	3	23	146	603
		500	3	44	156	459
80	California white pine	100	3	21	127	391
		500	3	43	163	603
81	Longleaf yellow pine	100	3	22	177	467
		500	3	43	196	516
82	Maple	100	4	23	177	522
		500	3	37	142	516
83	Oak	100	3	22	155	461
		500	3	40	162	552
84	Cedar	100	3	22	210	548
		500	3	40	221	725

[2] Maximum rate of pressure rise was not determined. The value for average rate is inserted as the maximum rate was equal to this at least.
[3] Test made at one concentration only.
[7] An indeterminable value.

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TABLE 1.—*Time-pressure data for various dusts*—Continued

WOOD, PAPER, TANNING MATERIALS, ETC.—Continued

Serial no.	Material	Concentration	Tests	Maximum pressure	Average rate of pressure rise	Maximum rate of pressure rise
		Mg per liter	*Number*	*Lb. per sq. in.*	*Lb. per sq. in. per sec.*	*Lb. per sq. in. per sec.*
85	Spruce	100	3	21	164	456
		500	3	39	145	456
86	Fir	100	3	18	117	265
		500	3	37	149	365
87	Cork	100	3	25	251	588
		500	7	40	185	518
88	Bagasse paper	100	3	16	81	175
		500	[3]	[3]	[3]	[3]
89	Sulphite cellulose	100	3	18	105	197
		500	3	29	129	220
90	Fustic wood	100	3	23	226	616
		500	3	39	198	527
91	Logwood	100	3	22	226	483
		500	3	36	133	447
92	Black oak bark	100	3	23	244	632
		500	3	38	141	412
93	Chestnut wood	100	3	27	242	856
		500	3	40	203	578
94	Chestnut oak bark	100	4	23	161	578
		500	3	39	144	467
95	Sumac leaf	100	7	20	156	350
		500	4	33	155	403
96	Quebracho-wood extract	100	3	23	174	531
		500	3	34	161	458
97	Chestnut-wood extract	100	3	22	162	408
		500	7	32	163	309
98	Wattle-bark extract	100	3	20	157	400
		500	4	33	181	434
	FERTILIZERS					
99	Soluble blood flour	100	4	26	189	357
		500	3	51	220	530
100	Raw bone	100	3	21	182	431
		500	3	39	230	503
101	Steamed bone	100	2	2	17	[2] (17)
		500	3	3	27	[2] (27)
102	Leather fertilizer	100	3	20	157	349
		500	3	36	209	506
103	Fish meal	100	8	17	115	188
		500	3	34	170	339
	RESINS, WAXES, SOAPS					
104	Soap powder	100	3	32	238	600
		500	4	42	164	325
105	Sodium resinate	100	3	31	185	430
		500	3	36	166	357
106	Candelilla wax	100	3	31	269	721
		500	3	33	128	284
107	Phenol aldehyde resin	100	3	28	268	648
		500	3	39	124	883
108	Shellac	100	3	27	184	854
		500	3	31	145	365
109	Carnauba wax	100	4	26	169	475
		500	[3]	[3]	[3]	[3]
110	Singapore gum	100	3	25	84	455
		500	7	38	197	397
111	Rosin	100	8	24	227	751
		500	3	32	164	438
	CARBON, COAL, ETC.					
112	Florida peat humus (artificially dried)	100	4	29	280	552
		500	3	48	404	954
113	Florida peat humus (air dried)	100	3	27	229	576
		500	3	44	304	653

[2] Maximum rate of pressure rise was not determined. The value for average rate is inserted as the maximum rate was equal to this at least.

[3] Test made at one concentration only.

TABLE 1.—*Time-pressure data for various dusts*—Continued

CARBON, COAL, ETC.—Continued

Serial no.	Material	Concentration	Tests	Maximum pressure	Average rate of pressure rise	Maximum rate of pressure rise
		Mg per liter	*Number*	*Lb. per sq. in.*	*Lb. per sq. in. per sec.*	*Lb. per sq. in. per sec.*
114	Wood charcoal	100	7	23	165	266
		500	8	42	146	294
115	Bituminous coal (Pittsburgh standard)	100	4	23	255	562
		500	3	42	252	538
116	Coal-tar pitch	100	3	22	177	344
		500	4	24	127	259
117	Coke	100	3	13	58	87
		500	3	26	69	117
118	Lampblack	100	3	10	73	119
		500	[3]	[3]	[3]	[3]
119	Carbon flour	100	3	4	28	[2] (28)
		500	3	3	23	[2] (23)
120	Graphite	100	2	2	[7]	[7]
		500	2	1	[7]	[7]
121	Anthracite	100	2	0	0	0
		500	2	0	0	0
122	Animal charcoal	100	2	0	0	0
		500	2	0	0	0
	METALS					
123	Aluminum	100	33	23	170	513
		500	21	40	240	724
124	Magnesium	100	3	23	140	469
		500	3	49	270	788
125	Iron	100	4	6	29	36
		500	3	19	62	105
126	Zinc	100	2	3	19	[2] (19)
		500	4	8	53	103
127	Gold bronze	100	2	2	12	[2] (12)
		500	2	3	20	[2] (20)
	MISCELLANEOUS					
128	Hard rubber (no. 1)	100	3	23	265	593
		500	3	37	248	504
129	Hard rubber (no. 2)	100	3	27	296	589
		500	3	36	270	671
130	Sulphur	100	3	17	101	230
		500	3	32	90	301
131	Lime-sulphur	100	3	16	102	222
		500	3	31	73	404
132	Ivory nuts	100	3	16	78	169
		500	3	33	154	601
133	Indigo	100	2	2	22	[2] (22)
		500	2	2	10	[2] (10)

[2] Maximum rate of pressure rise was not determined. The value for average rate is inserted as the maximum rate was equal to this at least.
[3] Test made at one concentration only.
[7] A indeterminable value.

Under Food Products and Byproducts, in table 1, the distinct differences in the figures on maximum pressure for powdered skim milk (46), powdered milk (48), and powdered whole milk (49) are noteworthy. The sample of powdered milk contained 16 percent of butterfat; hence this was intermediate in butterfat content between powdered skim milk and powdered whole milk. The analysis of the powdered whole milk, as stated on the label, follows: Butterfat, 28.20 percent; milk sugar, 37.88 percent; casein, 21.22 percent; albumin, 5.45 percent; ash, 5.75 percent; moisture, 1.50 percent. It has been found that various samples of both powdered skim milk and powdered

whole milk can produce either low pressures or distinctly high pressures. Evidently different manufacturing processes cause variation in explosibility, probably by affecting the dispersability. The same observation may apply to other materials. On account of the vast amount of work entailed, and its doubtful value, it was not considered advisable to run several samples of each material in the list. However, there are good reasons for believing that the results as a whole are representative. At the lower concentration, powdered milk (48) and bran (9) are at the bottom of the list. Higher, but still rather low figures, are shown by the meals, namely, cottonseed (44), linseed (43), copra (42), and yellow corn meal (18), and also by dextrin (37), oat hulls (29), egg albumen (41), and lactose (36). Some of these outstandingly low figures are not relatively maintained at the higher concentration. Some of them, such as those for bran and oat hulls, can probably be explained on the basis of high ash content. High nitrogen content along with some sticking of the particles may account for the egg-albumen figure. A tendency to stick and not disperse readily may account for the figures for the meals and dextrin.

There is not much variation among food products and byproducts as a whole, the maximum pressure in the majority of cases running from 19 to 26 pounds per square inch on the 100-milligram-per-liter concentration, and 35 to 45 pounds per square inch on the 500-milligram-per-liter concentration. The general similarity in behavior of casein (50), powdered skim milk (46), and powdered buttermilk (47) is shown. Among the sugars, the general behavior of sucrose (33), dextrose (35), and levulose (34) is similar, but lactose (36) stands out with much lower figures. Since lactose exists ordinarily as monohydrate, the low figure for this sample may be partly accounted for by the presence of this water of constitution. Cellulose (1) is outstandingly high; the sample was stated to be practically pure cellulose containing some coloring matter and about 0.75 percent of ash. The figures for spring wheat flour (7), hard and soft winter wheat flour (5 and 6), and wheat starch (4) are all close, although at 500 milligrams per liter the average and maximum rates on wheat starch are higher. Whole-wheat flour (8) runs considerably below the group above, probably partly on account of the higher ash content. Tapioca (24), rye (23), and barley (20) flours run about the same as the wheat flours other than whole-wheat; barley tends to be lower and tapioca higher at 100 milligrams per liter on the average and maximum rates. Buckwheat (25) and soybean (26) flours run lower than the cereal flours, the soybean flour being dispersed with some difficulty. On the whole, the starches behave alike, except that potato starch (3) is somewhat lower than the others, probably because it is less readily dispersable. The elevator dusts are generally comparable to the starches and the cereal flours. Barley elevator dust (21) is considerably lower than the others.

In the group of spices, drugs, insecticides, etc., dusts having low maximum pressures at the lower concentration are tobacco-stem dust (75) and smoking tobacco (74). Certain samples of tobacco produce considerably higher pressures. Apparently this is largely due to differences in dispersability, although differences in ash and nitrogen content may have some effect. Low dispersability probably accounts for the low result on ginger (61). The results on some

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other materials can be accounted for on the same basis and on the basis of high nitrogen or ash content. Some of the spices, such as allspice (59) and cloves (58), are oily and hence do not disperse readily. Very free-flowing materials, such as lycopodium (62) and cinnamon (51), produce correspondingly high maximum pressures. These differences disappear to a large extent at concentrations of 500 milligrams per liter, except that tobacco-stem dust (75) is still practically inert.

The woods, barks, and related materials are remarkably and rather uniformly high. Some of the long-fibered materials, such as bagasse paper (88), fir (86), and spruce (85), show figures somewhat below those of most of the other materials, especially at the lower concentration.

In the fertilizer group, the striking difference between raw and steamed bone (100 and 101) is brought out. The almost complete elimination of gelatin and other proteins and of fats from the raw bone by steaming reduces the explosibility very low. On the moisture-free basis the ash content of the raw bone was 48 percent; of the steamed bone, 76.3 percent. Soluble blood flour (99) stands out as having the highest maximum pressure. Leather fertilizer (102), raw bone (100), and fish meal (103) rank somewhat lower. These relations hold in a general way, although magnified to a considerable extent, for the rates of pressure rise. Soluble blood flour and raw bone were extremely fine powders. In these and other instances the pressures may be somewhat greater than they would be for coarser material. In other words, these 200-mesh materials may vary in fineness, some apparently being considerably finer than 200 mesh.

The resins, waxes, and soaps all have high maximum pressures, although figures for the 500-milligram concentrations are not very markedly above those for 100 milligrams. Soap powder (104) and sodium resinate (105) behave similarly. The sticking of the particles and fusion during combustion of some of these materials have a tendency to produce results that are erratic and generally lower than they otherwise would be.

Among the carbons and coals, the lowest figures for maximum pressure are those for carbon flour (119), graphite (120), animal charcoal (122), and anthracite (121). It will be noted that these materials are all very low in volatile matter and hard to ignite when in the form of a cloud and with a relatively small source of ignition. Moreover, animal charcoal has a high ash content. Why the wood charcoal (114) should produce such relatively high pressures is not quite clear, unless the highly adsorptive particles have much oxygen already on them or the ignition temperature is rather low. The peat-humus (112 and 113) samples are the highest in this group, followed by wood charcoal, bituminous coal (115), and coal-tar pitch (116). Coke (117) and lampblack (118) are intermediate. Substantially the same reasons may account for the coke figures as the wood-charcoal figures. The reason for the behavior of lampblack is not clear. At the higher concentration the maximum pressures of coke and coal-tar pitch are very similar. So far as general order is concerned, the observations that can be made with regard to average rate and maximum rate of pressure rise are similar to those in regard to maximum pressure, although there is no exact correspondence in the majority of cases.

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Among the metals, aluminum (123) and magnesium (124) are in a class by themselves in that they are much higher in regard to all three categories, maximum pressure, average rate, and maximum rate. Iron (125) is considerably higher than zinc (126), and gold bronze (127) is lowest of all. These results are in general agreement, so far as order of explosibility goes, with the heats of combustion as published. This is to be expected, since the dispersability would be similar throughout. Owing to greater density, the difficulty of dispersing the gold bronze, zinc, and iron would be somewhat greater than in the case of aluminum and magnesium; this, however, is taken care of partly by differing injection pressures.

Under "miscellaneous", the two samples of hard rubber (128 and 129) show good agreement. The sulphur (130) and the lime-sulphur (131) agree well, although the explosibility of these is considerably less than that of the two samples of rubber. The pressures of the ivory nut dust (132) are comparable to those produced by sulphur. Indigo (133), the only dye in this survey, is almost inert. However, other dyes and dye intermediates tested in this laboratory have produced considerably higher pressures.

The number of tests per sample averaged 3.7 for each concentration. In an attempt to evaluate the degree of reproducibility of each test, the percentage deviation range, which is the difference between highest and lowest, referred to the average and expressed as percentage, was divided by the number of tests, thus furnishing the deviation range per test. This range is considerably higher for the rates of pressure rise than for maximum pressures, hence allowance must be made for this fact in interpreting the results. These deviations are as follows:

	Average deviation range per test—percent
Maximum pressure at 100 milligrams per liter	7. 1
Maximum pressure at 500 milligrams per liter	4. 8
Average rate at 100 milligrams per liter	13. 7
Average rate at 500 milligrams per liter	12. 7
Maximum rate at 100 milligrams per liter	13. 4
Maximum rate at 500 milligrams per liter	12. 9

In the above a slight tendency is noted to greater variation at a concentration of 100 milligrams than at 500 milligrams per liter. The figures given above are the average of the deviation ranges for all samples; for some materials the range is considerably lower than this average figure, and in a few cases the range is much higher than the average.

With the exception of certain low values, which there is reason to believe are insignificant in regard to explosibility, the range of values for each category, maximum pressure, average rate of pressure rise, and maximum rate of pressure rise, at each concentration has been divided into 10 classes. For maximum pressure at 100 milligrams per liter, from 0 to 2 pounds per square inch, inclusive, is considered the base line (class 0), since for these low pressures there is nothing more than local burning around the ignition source, and there is no propagation of flame. The remaining pressures are divided into 10 classes, each having a range of 3 pounds except the top class, which extends over 4 pounds. For the reason previously mentioned, from 0 to 2

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pounds per square inch, inclusive, is considered the base line (class 0) for maximum pressure at a concentration of 500 milligrams per liter. The remaining pressures are divided into 10 classes, each having a range of 5 pounds. For average rate of pressure rise at 100 milligrams per liter, from 0 to 17 pounds per square inch per second, inclusive, is considered the base line (class 0), since the two lowest dusts whose rates could be determined, steamed bone and gold bronze, are in class 0 on maximum pressure. Those whose rates were so low as to be indeterminable are of course placed in class 0. The remaining inclusive figures are divided into 10 classes having a range of 33 pounds per square inch per second each. For average rate of pressure rise at concentrations of 500 milligrams per liter, from 0 to 10 pounds per square inch per second, inclusive, is considered the base line (class 0) for the reason given previously (average rate, 100 milligrams per liter). The remaining figures are divided into 10 classes of 47 pounds per square inch per second each. For maximum rate of pressure rise at 100 milligrams per liter, there are 10 classes of 84 pounds per square inch per second each. For maximum rate of pressure rise at 500 milligrams per liter there are 10 classes of 130 pounds per square inch per second each.

Table 2 summarizes the inclusive figures used for division into the various classes. Table 3 shows the classes under the various categories and indicates the great variation, in many materials, in the classes under the 2 concentrations and the 3 categories.

TABLE 2.—*Classification of explosive dusts on the basis of time-pressure data*

Class no.	100 mg per liter			500 mg per liter		
	Maximum pressure	Rate of pressure rise		Maximum pressure	Rate of pressure rise	
		Average	Maximum		Average	Maximum
	Lb. per sq. in.	*Lb. per sq. in. per sec.*	*Lb. per sq. in. per sec.*	*Lb. per sq. in.*	*Lb. per sq. in. per sec.*	*Lb. per sq. in. per sec.*
1	3–5	19–51	25–108	3–7	20–66	103–232
2	6–8	52–84	109–192	8–12	67–113	233–362
3	9–11	85–117	193–276	13–17	114–160	363–492
4	12–14	118–150	277–360	18–22	161–207	493–622
5	15–17	151–183	361–444	23–27	208–254	623–752
6	18–20	184–216	445–528	28–32	255–301	753–882
7	21–23	217–249	529–612	33–37	302–348	883–1, 012
8	24–26	250–282	613–696	38–42	349–395	1, 013–1, 142
9	27–29	283–315	697–780	43–47	396–442	1, 143–1, 272
10	30–33	316–348	781–864	48–52	443–489	1, 273–1, 402

TABLE 3.—*Classification of dusts by various categories according to explosibility*

[Arranged by classes in decreasing order of maximum pressures at 100 mg per liter]

Material	Maximum pressure		Average rate		Maximum rate	
	100 mg per liter	500 mg per liter	100 mg per liter	500 mg per liter	100 mg per liter	500 mg per liter
Alkali starch	(1)	9	(1)	10	(1)	8
Lycopodium	10	7	10	4	10	3
Soap powder	10	8	7	4	7	2
Sodium resinate	10	7	6	4	5	2
Candelilla wax	10	7	8	3	9	2
Cellulose	9	9	9	9	10	8
Gelatin	9	(1)	6	(1)	6	(1)

[1] Test made at one concentration only.

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TABLE 3.—*Classification of dusts by various categories according to explosibility*—Continued

Material	Maximum pressure		Average rate		Maximum rate	
	100 mg per liter	500 mg per liter	100 mg per liter	500 mg per liter	100 mg per liter	500 mg per liter
Chestnut wood	9	8	7	4	10	4
Shellac	9	6	6	3	10	3
Phenol aldehyde resin	9	8	8	3	8	7
Florida peat humus (air-dried)	9	9	7	7	7	5
Florida peat humus (artificially dried)	9	10	8	9	7	7
Hard rubber (no. 2)	9	7	9	6	7	5
Powdered skim milk	8	8	6	5	6	3
Rice starch	8	8	7	5	7	6
Sage	8	8	5	4	5	3
Cinnamon	8	9	9	6	10	4
Cinchona bark	8	7	7	4	8	3
Balsa	8	(1)	5	(1)	5	(1)
Redwood	8	8	8	6	6	5
Cork	8	8	8	4	7	4
Soluble blood flour	8	10	6	5	4	4
Carnauba wax	8	(1)	5	(1)	6	(1)
Rosin	8	6	7	4	9	3
Singapore gum	8	8	2	4	6	3
Hard winter wheat flour	7	8	4	5	5	4
Soft winter wheat flour	7	7	5	4	4	4
Wheat smut (no. 1)	7	8	3	4	4	4
Wheat smut (no. 2)	7	(1)	3	(1)	6	(1)
Cornstarch	7	9	5	8	7	6
Corn-elevator dust	7	9	7	6	7	6
Cornstalk flour	7	8	5	6	4	5
Oat dust from dry kiln	7	9	6	7	7	6
Malt	7	7	5	4	5	4
Casein	7	8	5	5	5	3
Sucrose	7	6	4	4	5	4
Agar	7	9	4	5	4	3
Nutmeg	7	8	5	5	4	4
Black pepper	7	9	6	5	5	3
Paprika	7	8	4	4	4	3
Squill	7	8	7	5	6	5
Gentian root	7	7	5	2	5	3
Hellebore	7	7	4	4	4	4
Tea fluff	7	7	4	4	5	3
Maple	7	7	5	3	6	4
White pine	7	9	4	3	7	3
Longleaf yellow pine	7	9	5	4	6	4
California white pine	7	9	4	4	5	4
Spruce	7	8	5	3	6	3
Oak	7	8	5	4	6	4
Cedar	7	8	6	5	7	5
Redwood bark	7	8	6	5	5	4
Logwood	7	7	7	3	6	3
Fustic wood	7	8	7	4	8	4
Chestnut oak bark	7	8	5	3	7	3
Black oak bark	7	8	7	3	8	3
Chestnut-wood extract	7	6	5	4	5	2
Quebracho-wood extract	7	7	5	4	7	3
Raw bone	7	8	5	5	5	4
Coal-tar pitch	7	5	5	3	4	2
Bituminous coal (Pittsburgh standard)	7	8	8	5	7	4
Wood charcoal	7	8	5	3	3	2
Aluminum	7	8	5	5	6	5
Magnesium	7	10	4	6	6	6
Hard rubber (no. 1)	7	7	8	5	7	4
Potato starch	6	8	4	6	5	5
Spring wheat flour	6	7	4	4	4	4
Wheat starch	6	8	4	6	4	6
Wheat-elevator dust	6	9	5	7	4	5
Rye flour	6	7	4	6	6	5
Barley flour	6	7	4	6	3	5
Dextrose	6	9	4	4	4	3
Levulose	6	9	4	7	4	5
Gluten meal	6	7	3	4	3	2
Cracker meal	6	8	3	5	3	3
Kafir corn	6	8	4	6	4	6
Tapioca flour	6	8	6	6	7	5
Oat-elevator dust	6	8	4	3	5	4
Powdered buttermilk	6	8	4	4	3	2
Oriental licorice root	6	6	4	3	4	3
Spanish licorice extract	6	9	4	4	3	3
Blood root	6	7	4	4	4	3
Pyrethrum	6	7	4	3	6	3
Buckthorn bark	6	8	5	3	4	4

[1] Test made at one concentration only.

TABLE 3.—*Classification of dusts by various categories according to explosibility*—Continued

Material	Maximum pressure		Average rate		Maximum rate	
	100 mg per liter	500 mg per liter	100 mg per liter	500 mg per liter	100 mg per liter	500 mg per liter
Cascara sagrada	6	9	6	5	5	5
Fir	6	7	3	3	3	3
Sumac leaf	6	7	5	3	4	3
Wattle-bark extract	6	7	5	4	5	3
Sulphite cellulose	6	6	3	3	3	1
Leather fertilizer	6	7	5	5	4	4
Whole-wheat flour	5	7	3	4	3	3
Buckwheat flour	5	7	3	4	2	4
Soybean flour	5	5	3	2	3	2
Alfalfa	5	6	3	3	2	2
Pectin	5	7	3	4	3	3
Powdered whole milk	5	6	3	3	3	3
Cardamom seed	5	7	2	5	3	4
Allspice	5	6	3	3	3	3
Cloves	5	6	4	2	3	3
Bagasse paper	5	(1)	2	(1)	2	(1)
Fish meal	5	7	3	4	2	2
Ivory nuts	5	7	2	3	2	4
Sulphur	5	6	3	2	3	2
Lime-sulphur	5	6	3	2	3	3
Barley-elevator dust	4	7	2	3	2	3
Peanut-hull flour	4	6	2	3	2	2
Yellow corn meal	4	7	2	4	2	3
Copra meal	4	4	2	2	2	1
Linseed meal	4	5	2	2	2	1
Oat hulls	4	7	2	3	2	2
Lactose	4	4	3	2	2	1
Dextrin	4	5	3	4	6	10
Egg albumen	4	6	2	3	1	2
Belladonna leaves	4	4	2	2	2	1
Althea root	4	5	2	2	2	2
Coke	4	5	2	2	1	1
Ginger	3	7	1	3	1	2
Lampblack	3	(1)	2	(1)	2	(1)
Cottonseed meal	2	4	1	2	1	1
Smoking tobacco	2	5	1	2	1	1
Iron	2	4	1	1	1	1
Powdered milk	1	(1)	1	(1)	1	(1)
Bran	1	6	1	3	0	2
Cocoa	1	5	1	2	1	1
Carbon flour	1	1	1	1	1	0
Zinc	1	2	1	1	0	1
Steamed bone	0	1	0	1	0	0
Tobacco-stem dust	0	0	0	0	0	0
Animal charcoal	0	0	0	0	0	0
Anthracite	0	0	0	0	0	0
Graphite	0	0	0	0	0	0
Gold bronze	0	1	0	1	0	0
Indigo	0	0	1	0	0	0

[1] Test made at one concentration only.

Table 4 shows the ratings based on the average of classification figures for the three categories. According to these ratings the various materials are placed in groups numbered from 1 to 10, each group representing a range of 10 on a scale of 100. For example, if a material is in class 2 on maximum pressure, class 2 on average rate, and class 3 on maximum rate, the average is 2.3 or, expressed on a scale of 100, the rating is 23, which places it in group 3. There is considerable difference in the order of materials and in their ratings for the two concentrations. Materials having a rating from 0 to 9 may be considered to be in one group, while those from 10 to 19 are in the next higher group. Any closer grouping than this is precluded by errors in measurement and, what is much more important, the erratic behavior of the materials in many cases. The last two columns of table 4 show a composite picture of the rating, based on both concentrations and all three categories.

TABLE 4.—*Ratings of explosibility of dusts based on average of classes as regards maximum pressure, average rate of pressure rise, and maximum rate of pressure rise*

[Maximum explosibility=100; minimum explosibility=0]

Material	Concentration of 100 mg per liter		Concentration of 500 mg per liter		Average for both concentrations	
	Group	Rating	Group	Rating	Group	Rating
Agar	6	50	6	57	6	53
Alfalfa	4	33	4	37	4	35
Allspice	4	37	5	40	4	38
Althea root	3	27	4	30	3	28
Aluminum [1]	7	60	7	60	7	60
Bagasse paper [2]	4	30	(3)	(3)	[3] 4	[3] 30
Balsa	7	60	(3)	(3)	[3] 7	[3] 60
Belladonna leaves	3	27	3	23	3	25
Black-oak bark	8	73	5	47	7	60
Blood flour, soluble	7	60	7	63	7	62
Blood root	5	47	5	47	5	47
Bone:						
Raw	6	57	6	57	6	57
Steamed	0	0	1	7	1	3
Bran	1	7	4	37	3	22
Buckthorn bark	6	50	6	50	6	50
Powdered buttermilk	5	43	5	47	5	45
Carbon flour	2	10	1	7	1	8
Cardamom seed	4	33	6	53	5	43
Cascara sagrada	6	57	7	63	7	60
Casein	6	57	6	53	6	55
Cedar	7	67	7	60	7	63
Cellulose	10	93	9	87	10	90
Charcoal:						
Animal	0	0	0	0	0	0
Wood	6	50	5	43	5	47
Chestnut-oak bark	7	63	5	47	6	55
Chestnut wood	9	87	6	53	8	70
Chestnut-wood extract	6	57	5	40	5	48
Cinchona bark	8	77	5	47	7	62
Cinnamon	10	90	7	63	8	77
Cloves	5	40	4	37	4	38
Coal:						
Anthracite	0	0	0	0	0	0
Bituminous (Pittsburgh standard)	8	73	6	57	7	65
Coal-tar pitch	6	53	4	33	5	43
Cocoa	2	10	3	27	2	18
Coke	3	23	3	27	3	25
Copra meal	3	27	3	23	3	25
Cork	8	77	6	53	7	65
Corn meal, yellow	3	27	5	47	4	37
Cottonseed meal	2	13	3	23	2	18
Cracker meal	5	40	6	53	5	47
Dextrin	5	43	7	63	6	53
Dextrose	5	47	6	53	6	50
Egg albumen	3	23	4	37	4	30
Elevator dust:						
Barley	3	27	5	43	4	35
Corn	8	70	8	70	8	70
Oat	6	50	6	50	6	50
Wheat	6	50	8	70	7	60
Fir	5	40	5	43	5	42
Fish meal	4	33	5	43	4	38
Flour:						
Barley	5	43	7	60	6	52
Buckwheat	4	33	6	50	5	42
Cornstalk	6	53	7	63	6	58
Hard winter wheat	6	53	6	57	6	55
Peanut hull	3	27	4	37	4	32
Rye	6	53	7	60	6	57
Soft winter wheat	6	53	6	50	6	52
Soybean	4	37	4	30	4	33
Spring wheat	5	47	6	50	5	48
Tapioca	7	63	7	63	7	63
Whole wheat	4	37	5	47	5	42
Fustic wood	8	73	6	53	7	63
Gelatin	8	70	(3)	(3)	[3] 8	[3] 70
Gentian root	6	57	5	40	5	48
Ginger	2	17	5	40	3	28
Gluten meal	5	40	5	43	5	42
Gold bronze	0	0	1	7	1	3
Graphite	0	0	0	0	0	0
Hellebore	6	50	6	50	6	50

[1] Not 200 mesh. [2] Coarser than 200 mesh. [3] Test made at 1 concentration only.

TABLE 4.—*Ratings of explosibility of dusts based on average of classes as regards maximum pressure, average rate of pressure rise, and maximum rate of pressure rise*—Continued

Material	Concentration of 100 mg per liter		Concentration of 500 mg per liter		Average for both concentrations	
	Group	Rating	Group	Rating	Group	Rating
Indigo	1	3	0	0	1	2
Iron	2	13	3	20	2	17
Ivory nuts	4	30	5	47	4	38
Kafir corn	5	47	7	67	6	57
Lactose	4	30	3	23	3	27
Lampblack	3	23	(3)	(3)	[3] 3	[3] 23
Leather fertilizer	6	50	6	53	6	52
Levulose	5	47	8	70	6	58
Licorice:						
Oriental, root	5	47	5	40	5	43
Spanish, extract	5	43	6	53	5	48
Lime-sulphur	4	37	4	37	4	37
Linseed meal	3	27	3	27	3	27
Logwood	7	67	5	43	6	55
Lycopodium	10	100	5	47	8	73
Magnesium	6	57	8	73	7	65
Malt	6	57	6	50	6	53
Maple	7	60	5	47	6	53
Powdered milk	2	10	(3)	(3)	[3] 2	10
Skim	7	67	6	53	7	60
Whole	4	37	5	40	4	38
Nutmeg	6	53	6	57	6	55
Oak	7	60	6	53	6	57
Oat dust from dry kiln	7	67	8	73	8	70
Oat hulls	3	27	5	40	4	33
Paprika	6	50	6	50	6	50
Peat humus, Florida:						
Air-dried	8	77	8	70	8	73
Artificially dried	9	80	9	87	9	83
Pectin	4	37	5	47	5	42
Pepper, black	7	60	6	57	6	58
Phenol aldehyde resin	9	83	7	60	8	72
Pine:						
California white	6	53	6	57	6	55
Longleaf yellow	7	60	6	57	6	58
White	7	60	6	50	6	55
Pyrethrum	6	53	5	43	5	48
Quebracho wood extract	7	63	5	47	6	55
Redwood	8	73	7	63	7	68
Redwood bark	7	60	6	57	6	58
Rosin	9	80	5	43	7	62
Rubber, hard:						
No. 1	8	73	6	53	7	63
No. 2	9	83	7	60	8	72
Sage	7	60	6	50	6	55
Shellac	9	83	5	40	7	62
Singapore gum	6	53	6	50	6	52
Soap powder	9	80	5	47	7	63
Sodium resinate	8	70	5	43	6	57
Spruce	7	60	5	47	6	53
Squill	7	67	7	60	7	63
Starch:						
Alkali	(3)	(3)	10	90	[3] 10	[3] 90
Corn	7	63	8	77	8	70
Potato	6	50	7	63	6	57
Rice	8	73	7	63	7	68
Wheat	5	47	7	67	6	57
Sucrose	6	53	5	47	6	50
Sulphite cellulose	5	40	4	33	4	37
Sulphur	4	37	4	33	4	35
Sumac leaf	6	50	5	43	5	47
Tea fluff	6	53	5	47	6	50
Tobacco:						
Smoking	2	13	3	27	3	20
Stem dust	0	0	0	0	0	0
Wattle bark extract	6	53	5	47	6	50
Wax:						
Candelilla	10	90	5	40	7	65
Carnauba	7	63	(3)	(3)	[3] 7	[3] 63
Wheat smut:						
No. 1	5	47	6	53	6	50
No. 2	6	53	(3)	(3)	[3] 6	[3] 53
Zinc	1	7	2	13	2	10

[3] Test made at 1 concentration only.

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The relative order of explosibility of the starches, flours, and elevator dusts may be readily seen in table 4. Among the sugars, dextrose, levulose, and sucrose are all in group 6, while lactose is much lower, in group 3. Powdered skim milk is in group 7, casein in group 6, powdered buttermilk in group 5, and powdered whole milk in group 4. Two materials that vary much in different categories are dextrin, which is in group 6, and bran, which is in group 3. Oat hulls and egg albumen are in the fourth group. The meals are low. Yellow corn meal is in the fourth group, copra and linseed meal are in the third, and cottonseed meal, the lowest, is in the second.

Among the spices, drugs, and related materials, lycopodium and cinnamon are high, each being in group 8. Allspice and cloves are in group 4. Ginger and smoking tobacco are in group 3. Cocoa is in group 2, and tobacco stem dust is in group 0.

With the exception of sulphite cellulose, in group 4, all the woods and related materials are in groups 5 to 8, inclusive. Fir, sumac leaf, and chestnut-wood extract are in group 5; the remainder are in 6 to 8, inclusive, chestnut wood being the only one in group 8.

Soluble blood flour, in the seventh group, ranks highest among the fertilizers. Leather fertilizer is in the sixth group, and fish meal is in the fourth. Raw bone is in group 6, but steamed bone is in group 1.

The resins as a class rate high. Phenol aldehyde resin is in the eighth group; carnauba and candelilla wax, rosin, and soap powder, are in the seventh group; and Singapore gum and sodium resinate are in group 6.

Among the carbons, artificially dried Florida peat humus is in the ninth group, and air-dried Florida peat humus is in the eighth. Pittsburgh standard bituminous coal is in group 7, wood charcoal and coal-tar pitch are in the fifth group, and coke is in the third. One of the carbons is in group 1, and three are in group 0.

Large differences are shown in the metals; magnesium and aluminum are in the seventh group, zinc and iron in the second, and gold bronze is in the first.

In the class of miscellaneous materials, hard rubber no. 2 is in group 8 and hard rubber no. 1 in group 7; sulphur and lime-sulphur, also ivory nut dust, are in group 4; indigo is in group 1.

Cellulose is the most dangerous material, having a rating of 90. It is the only material in the tenth group. Florida peat humus (artificially dried) is in the ninth group, with a rating of 83. Of the 8 materials in group 1 and group 0, 4 are carbons and 1 is a metal.

Tables 5, 6, and 7 present data of interest. The time per test as shown in table 5 varies widely. The average time for average rate at 500 milligrams per liter is about one and one-half that at 100 milligrams per liter (table 5). At the maximum rate the average time at the higher concentration is not much greater than at the lower concentration. The time for maximum rate at 100 milligrams per liter is about one-fifth the time for average rate at the same concentration.

TABLE 5.—*Time in seconds for average rate and maximum rate of pressure rise*

Rate of pressure rise	Lowest	Highest	Average
Average rate (100 mg per liter)	0.060	0.384	0.150
Average rate (500 mg per liter)	.076	.531	.220
Maximum rate (100 mg per liter)	.007	.269	.032
Maximum rate (500 mg per liter)	.007	.212	.037

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TABLE 6.—*Ratio of maximum rate to average rate of pressure rise* [1]

Concentration	Lowest	Highest	Average
100 mg per liter	1.0	5.4	2.3
500 mg per liter	1.0	7.1	2.7

[1] Ratio of the average of the values for the various materials.

TABLE 7.—*Ratio of 500-mg-concentration values to 100-mg-concentration values* [1]

Pressure and rate of pressure rise	Lowest	Highest	Average
Maximum pressure	0.5	7.5	1.9
Average rate of pressure rise	.5	5.3	1.4
Maximum rate of pressure rise	.4	4.8	1.6

[1] Ratio of the average of the values for the various materials.

Table 6 gives ratios of maximum rate to average rate. For both concentrations, the resins had the highest ratios, Singapore gum at 100 milligrams per liter and phenol aldehyde resin at 500 milligrams per liter. The lowest ratios were for materials whose maximum rate was so close to the average rate that it was impossible to differentiate the two. The average ratio at 500 milligrams per liter is not much greater than at 100 milligrams per liter. Table 7 gives the ratio of 500-milligram values to 100-milligram values, and shows the great effect of the concentration of dust in air on the maximum pressure and the average and maximum rates of pressure rise.

The average ratio of 500-milligram-per-liter values to 100-milligram-per-liter values is between 1.4 and 1.9, being lowest in the average rate and highest in the maximum pressure. The highest ratios range from 4.8 to 7.5; the lowest are 0.4 and 0.5. Bran has the highest ratio for both average rate and maximum pressure; cocoa has the highest ratio for maximum rate. The lowest ratios are held by graphite, shellac, phenol aldehyde resin, and candelilla wax. Candelilla wax has the lowest value for both average rate and maximum rate. This shows the value of testing dusts with at least two concentrations of dust in air.

SUMMARY AND CONCLUSIONS

An apparatus and method are described for the determination of the explosibility of dusts.

In addition to the maximum pressure developed on explosion, average rate and maximum rate of pressure rise are taken as criteria of explosibility.

The explosibility of 133 dusts was determined at two concentrations, 100 and 500 milligrams of dust per liter of air.

To compare the explosibility of dusts, three important factors that enter into an explosive reaction should be taken into consideration, namely, the maximum pressure developed on explosion, the average rate of pressure rise, and the maximum rate of pressure rise.

A study of the structural damage caused by dust explosions has shown that the rate of pressure rise, which may be called the dynamic load, is responsible to a large extent for the damage done. If the

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rate of rise is sufficiently low, the load on the structure may be released by the blowing out of windows without causing further damage; if the rate of rise is high enough and if the pressure cannot be released sufficiently by windows or other vents, structural damage will occur. For these reasons, the rates of pressure rise, in addition to the maximum pressure, are given as criteria of explosibility.

The ratio of 500-milligram value to 100-milligram value given in table 7 shows the desirability of making explosibility tests at more than one concentration of dust in air. In some cases the values for maximum pressure and average rate or maximum rate of pressure rise at a concentration of 500 milligrams per liter are about 0.5 the values obtained at the 100-milligram-per-liter concentration; while with another dust the pressure developed with a 500-milligram-per-liter concentration is 7.5 times that developed at 100 milligrams per liter. Since the tests reported in this bulletin were made at both concentrations, it is believed that they have more significance than those made at one concentration.

Any hard and fast classification seems impossible at present on account of rather large errors in individual determinations, which were largely due to difficulties in producing uniformly reproducible dispersions of the same dust, and on account of the range in values among various samples of the same material. Hence any material placed in a certain class or group in the 11 divisions may have an uncertainty, which does not exceed, as a rule, plus or minus one class or group. Of course much more consistent results are obtained with some dusts than with others. However, it is believed that the data, especially that summarized in table 4, will be of considerable value in expressing the dust-explosion hazards inherent in various materials.

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EARLY DEVELOPMENTAL STAGES OF NEMATODES OCCURRING IN SWINE

By

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Zoological Division
Bureau of Animal Industry

UNITED STATES DEPARTMENT OF AGRICULTURE, WASHINGTON, D. C.

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INTRODUCTION

The object of this bulletin is to present the results of an investigation on the early developmental stages of nematodes of common occurrence in domestic swine. Observations on the stages in the definitive host of two of the nematodes, *Gongylonema pulchrum* and *Hyostrongylus rubidus*, are only briefly given, however, since little is known of these stages in these nematodes. The nomenclature of each parasite, its host relationship, geographic distribution, morphology, and bionomics of its early stages are discussed.

In addition to the scientific interest attaching to the new findings presented here, there is an economic aspect of considerable importance in that a knowledge of the life history and bionomics is essential in formulating control measures for these parasites, many of which are distinctly pathogenic.

Unless otherwise stated, all work was done in the laboratories of the Zoological Division at Washington, D. C.

[1] The material in this bulletin was presented as a thesis in January 1934 to the faculty of the Graduate School of the George Washington University in partial fulfillment of the requirements for the degree of doctor of philosophy. The writer is indebted to associates in the Zoological Division for suggestions and constructive criticisms in its preparation. R. E. Snodgrass, of the Bureau of Entomology and Plant Quarantine, supplied valuable information in connection with the study of the mode of encystment of *Gongylonema* larvae in the muscle of an insect host. E. A. Chapin, also of the same Bureau, identified various species of Coleoptera. Frank Smith, formerly professor at the University of Illinois, identified earthworms used in connection with studies of the life history of *Metastrongylus salmi*.

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HISTORICAL RÉSUMÉ

The existing knowledge concerning the development and bionomics of swine nematodes has been accumulated within less than a century. One of the early life-history studies was that of *Trichinella spiralis*. Leidy (*1*)[2] in 1847 observed encysted larvae of *T. spiralis* in the body musculature of the pig; these encysted larvae were described, however, in 1835 by Owen (*85*) from similar findings in the human muscle. The cysts of *T. spiralis* were first found in human muscle by Tiedman in 1822 and by Peacock in 1828. According to Cobbold (*18*), Tiedman probably saw the calcified cysts of *T. spiralis*. Experiments on the transmission of *T. spiralis* were performed by Herbst (*46, 47*) in 1851 and 1852, Virchow (*2, p. 430*) in 1859, Leuckart (*58, 59*) in 1860 and 1866, and Zenker (*142*) in 1860.

The first investigation relative to the development of *Ascaris* eggs was undertaken by Schubart and Verloren in 1854, cited by Küchenmeister (*56*), on the dog ascarid, *Toxocara canis*. Richter in 1854, cited by Küchenmeister (*56*), and Davaine (*23*) in 1859, were apparently the first to note the development of the ascarid of man.

Numerous investigations have been carried out on the resistance of *Ascaris* eggs to various environmental conditions. The ascarids of man and of swine were reported to be resistant to low temperatures by Davaine (*23*), Leuckart (*60, v. 2, lfg. 3*), Yoshida (*139*), Martin (*72*), Cram (*22*), and Raffensperger (*89*). The resistance of ascarid eggs to various chemicals has been noted by Galli-Valerio (*31*), Yoshida (*139*), Wharton (*136*), Kobayashi (*54*), and Ransom and Foster (*97*). The resistance of ascarid eggs to dryness has been recorded by Ross (*102*), Ransom and Foster (*97*), Martin (*73*), and others. Reports that ascarid eggs remain alive for long periods, even for several years, were published by Brown (*13*), Leuckart (*60*), Epstein (*24*), Morris (*78*), Ransom and Foster (*97*), Fülleborn (*28*), Martin (*73*), and others.

According to Linstow (*63*) in 1886, the myriapod *Julus guttulatus* and the closely allied species *Polydesmus complanatus* probably served as intermediate hosts for *Ascaris lumbricoides*. Stewart (*126, 127, 128, 129*) in 1916–18, reported that larvae of *A. lumbricoides* migrated to the lungs and appeared in the mouth or feces of the rat or mouse. He surmised that these larvae got on to the food of human beings from these hosts, and when swallowed with such food the larvae completed development in the intestine of the definitive host. Ransom and Foster (*95, 96*) in 1917 and 1919, and Ransom and Cram (*93, 94*) in 1921, contrary to Linstow and Stewart, demonstrated that the life history of *Ascaris* was direct.

One of the earliest investigations on the development of *Trichuris* eggs was made in 1858 on those of *T. trichiura* by Davaine (*23*). Leuckart (*60*) in 1876 showed that infection with *T. ovis* and *T. suis* followed after a feeding of embryonated eggs of these parasites to their respective hosts. Railliet (*91*) in 1884 obtained similar results with *T. vulpis* in dogs, and Grassi (*38*) in 1887 noted similar results with *T. trichiura* in man.

With reference to the life history of *Gongylonema pulchrum*, Stiles (*131*) in 1892, was of the opinion that this nematode was heteroxen-

[2] Italic numbers in parentheses refer to Literature Cited, p. 89.

ous. It was not until 1915 that Ransom and Hall (*98*) reported that dung beetles served as intermediate hosts for this parasite. They also noted that the life history of *Gongylonema* was strikingly similar to that of *Spiroptera obtusa* which, according to Leuckart (*60*) and Marchi (*71*), required the meal worm (larva of *Tenebrio molitor*) as the intermediate host.

The life histories of *Physocephalus sexalatus* and *Ascarops strongylina*, involving various species of dung beetles as intermediate hosts, were elucidated by the findings of Seurat (*115*, *116*, *117*), in 1913, 1915, and 1916.

The life histories of the swine lungworms *Metastrongylus elongatus* and *Choerostrongylus pudendotectus* were unsolved until recently. Leuckart (*60*) in 1876, believed these lungworms to be heteroxenous and suggested that an insect or snail might serve as the intermediate host. Several writers, namely, Von Linden and Zenneck (*62*) in 1915, Herms and Freeborn (*48*) in 1916, and Zebrowski (*140*, *141*) in 1922 and 1925, were of the opinion that the swine lungworm larvae developed into a free-living generation. It was not until 1929 that Hobmaier and Hobmaier (*49*, *50*) reported that earthworms served as intermediate hosts of *M. elongatus* and *C. pudendotectus*. Their work was confirmed by Schwartz and Alicata (*109*, *111*) in 1929 and 1931, and by Von Schuckmann and Zunker (*106*) in 1930. In the work reported in this bulletin the present writer has found that *Metastrongylus salmi*, another swine lungworm, also requires earthworms as intermediate hosts. Alessandrini (*3*) noted that long ago Cobbold considered earthworms as possible intermediate hosts.

The first observation on the preparasitic larval stages of *Stephanurus dentatus* was made in 1900 by Tayler (*133*), who gave a brief description of the hatching and morphology of these larvae. More extensive investigations on the developmental stages and bionomics of *S. dentatus* have been reported by Bernard and Bauche (*11*) in 1913 and 1914, Schwartz and Price (*112*, *113*, *114*) in 1928, 1929, and 1931, Ross and Kauzal (*100*, *101*) in 1929 and 1932, and Spindler (*124*, *125*) in 1931 and 1933.

There is very little literature relating to the life cycle of *Hyostrongylus rubidus*. Schang (*104*) in 1927 attempted to trace the larval development of this parasite, but from his description and illustrations it is evident that he had confused larvae of *H. rubidus* with those of free-living nematodes. Goodey (*37*), in the same year, gave a brief but accurate description of the preparasitic larval stages and bionomics of *H. rubidus*, in spite of the fact that he was dealing with very limited numbers of larvae. His finding showed that the preparasitic larval stages of *H. rubidus* were similar in general to those of other known strongyles.

Literature concerning the life history of *Oesophagostomum dentatum* is also very scarce. An accurate description of the preparasitic larval stages of this parasite and a discussion of their bionomics were given by Goodey (*36*) in 1924.

With reference to *Strongyloides ransomi*, Schwartz and Alicata (*110*), in 1930, noted that eggs derived from parasitic females developed either to strongyliform larvae or to free-living sexually mature worms, the progeny of the latter developing into strongyliform larvae capable of infecting the host.

GENERAL REMARKS ON LIFE HISTORIES OF GROUPS STUDIED

The nematodes known from swine include representatives of several large groups of parasitic nematodes. As would be expected in view of this fact, a considerable variety of life histories was found in the writer's investigation.

The nematodes discussed in this bulletin include seven families, and on the basis of life history they may be subdivided into the heteroxenous and monoxenous groups.

The heteroxenous group includes the families Spiruridae (represented by *Gongylonema pulchrum*, *Ascarops strongylina*, and *Physocephalus sexalatus*) and Metastrongylidae (represented by *Metastrongylus salmi*, *M. elongatus*, and *Choerostrongylus pudendotectus*).

The life history of the heteroxenous group may be of the following type: Adult male and female in definitive host; embryonated eggs outside of definitive host; first-, second-, and third-stage larvae in intermediate host; third- and fourth-stage larvae and adult males and females (fifth stage) in definitive host. Each larval stage except the first one is separated from the previous stage by a molt; two molts occur in the intermediate host, and two in the definitive host. The sheath of the second molt in the members of the Spiruridae is completely cast off, apparently because these larvae are protected in the body of the intermediate host by a cyst wall. In the third-stage larvae of the Metastrongylidae, the sheath of the second molt is retained.

The monoxenous group includes the families Ascaridae (represented by *Ascaris suum*), Trichuridae (represented by *Trichuris suis*), Trichostrongylidae (represented by *Hyostrongylus rubidus*), Strongylidae (represented by *Oesophagostomum dentatum* and *Stephanurus dentatus*), and Strongyloididae (represented by *Strongyloides ransomi*). Larvae of the monoxenous group show considerable variation in their mode of development before entering the host.

The eggs of the Ascaridae and Trichuridae are deposited with the feces of the host, and after becoming fully embryonated are capable of producing an infection when ingested by suitable hosts. The *Ascaris* embryo molts once while in the eggshell and is not infective until after this molt.

The life history of the Trichostrongylidae and Strongylidae families may be as follows: Adult male and female in host; segmenting eggs and first-, second-, and third-stage larvae outside of host; third- and fourth-stage larvae and adult males and females (fifth stage) in host. The preparasitic larval stages are separated by two molts, the sheath of the second molt being retained in most cases so that third-stage larvae are usually enclosed within a sheath. The parasitic stages also are separated by two molts.

The Strongyloididae group of nematodes has a heterogonous life history. In *Strongyloides ransomi*, larvae derived from eggs of parasitic females pursue one of two cycles of development, direct or indirect. In the direct cycle, the larvae develop as in the Strongylidae. In the indirect cycle, the larvae develop into free-living adults; the progeny of the latter develop as in the Strongylidae.

Throughout this bulletin the writer has followed for the most part the classification of the parasitic nematodes of vertebrates as given by Yorke and Maplestone (*138*). The lists of synonyms, hosts, and location and distribution of the various parasites discussed, have been taken for the most part from Hall (*42*, *43*).

ABBREVIATIONS AND SYMBOLS USED IN ILLUSTRATIONS

adbp, anterior dorsal body papilla
ao, anal opening
amph, amphid
angl, anal ganglion
b, base
bc, buccal cavity
bcp, buccal capsule
clgl, cephalic lateral ganglion
cp, cervical papilla (deirid)
csdgl, cephalic subdorsal ganglion
csvgl, cephalic subventral ganglion
cstwl, cyst wall
cutb, cuticular bosses
dbp, dorsal body papilla
dgl, dorsal ganglion
esh, egg shell
epc, epithelial cell
es, esophagus
excnu, excretory cell nucleus
exgl, excretory gland
exp, excretory pore
exs, excretory sinus
fgp, female genital primordium
gc^1, first giant cell
gc^2, second giant cell
gc^3, third giant cell
gc^4, fourth (genital) giant cell
gp, genital primordium
germ, germinal cell
gon, gonoduct
gub, gubernaculum
h, hook
insmu, insect muscle
int, intestine
lgl, lateral ganglion
lbgl, lumbar ganglion
lv, larva
mgp, male genital primordium
mthelev, mouth elevation
nr, nerve ring
orop, oral opening
ov, ovary
ovj, ovejector
p, papilla
pdbp, posterior dorsal body papilla
plgl, postero-lateral ganglion
prbcp, provisional buccal capsule
pres, proesophagus
ptes, postesophagus
pvgl, postero-ventral ganglion
rgd, rectal gland
rch, rachis
rvgl, retrovesicular ganglion
sv, seminal vesicle
sdgl, subdorsal ganglion
sdp, subdorsal papilla
sp, spicule
spa, spicule primordium
spr, spear
svgl, subventral ganglion
svp, subventral papilla
t, tail
tp, tail process
tel, telamon
ts, testis
ut, uterus
v, vulva
vdf, vas deferens
ve, vas efferens

MORPHOLOGICAL AND EXPERIMENTAL DATA

SPIRURIDAE

GONGYLONEMA PULCHRUM MOLIN, 1857

(Figs. 1–9)

Synonyms.—*Gongylonema filiforme* (?) Molin, 1857; *G. spirale* (?) Molin, 1857; *Filaria labialis* Pane, 1864; *Spiroptera scutata* Müller, 1869; *F. scutata* (Müller, 1864) Leuckart, 1873; *G. scutatum* (Müller, 1869) Railliet, 1892; *Myzomimus scutatus* (Müller, 1869) Stiles, 1892; *G. ursi* (?) (Dujardin, 1845) Neumann, 1894; *G. confusum* Sonsino, 1896; *G. subtile* Alessandrini, 1914; *G. hominis* Stiles, 1921; *G. ransomi* Chapin, 1922.

Hosts.—Definitive: Sheep, goat, ox, camel, fallow deer, buffalo, zebu, chevrotain, pig, wild boar, horse, donkey, bear(?), macaque, *Ateles* sp., *Pithecus entellus*, man, white rat, guinea pig, and rabbit. Intermediate: Coleoptera (*Aphodius coloradensis*, *A. distinctus*, *A. femoralis*, *A. fimetarius*, *A. granarius*, *A. rubeolus*,

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A. vittatus, *Blaps appendiculata*, *B. emondi*, *B. strauchi*, *Caccobius schreiberi*, *Oniticellus fulvus*, *Onthophagus hecate*, *O. pennsylvanicus*, *O. taurus*(?), *Sphaerius* sp., and *Sphaeridium* sp.); and Orthoptera (*Blatella germanica*). Intermediate hosts reported for *Gongylonema* sp., probably *G. pulchrum: Aphodius haemorrhoidalis*, *Gymnopleurus* sp., *Blatta orientalis*, and *Periplaneta americana*. Accidental: Mammals; nematode larvae collected by A. McIntosh from the stomach wall of a mole (*Scalopus aquaticus aquaticus*) were identified by the writer as third-stage larvae of *Gongylonema* sp.

In addition to the above-mentioned intermediate hosts the following insects have been found by the writer to serve as intermediate hosts for *G. pulchrum: Aphodius lividus*, *Dermestes vulpinus*, *Parcoblatta* sp.

Location.—Adults in mucosa of esophagus, tongue, and oral cavity of definitive host; third-stage larvae in body cavity of intermediate host.

Distribution.—Africa, Asia, Australia, Europe, and North America (United States).

Description of Egg, Embryo, and Larval Stages

EGG

Egg elliptical in shape; shell about 3μ thick, with smooth surface (fig. 1, *A*)- Under high-power magnification, a faint line can be made out at each pole, repre. senting the operculum. In a series of measurements involving about 50 eggs, length 57μ to 59μ, width 30μ to 34μ. Each egg contains a well-developed embryo at time of oviposition.

EMBRYO

Embryos (fig. 1, *F*), obtained by crushing several eggs on a slide under a cover slip, 240μ to 280μ long by 13μ in maximum width. Embryo does not undergo additional development before being ingested by intermediate host. Morphology of embryo corresponds to that of young first-stage larva.

FIRST-STAGE LARVA

Shape and size.—Newly hatched larva slender and of same width for most of length. As it grows during this stage, posterior half grows more in width than does anterior half, giving larva a club-shaped appearance (fig. 2, *A* and *B*). Anterior end broadly rounded, posterior portion tapering slightly and ending in a rounded extremity. Size of larva depends on degree of development (table 1); before molting, first-stage larva sometimes attains a length of 540μ and a width of 38μ.

Cuticle.—Very thin, transparent, with very fine transverse striations; anterior end of ventral portion with 1 spine and 2 small hooks of various sizes arranged longitudinally (fig. 1, *B* and *C*). When viewed with oil-immersion lens, spine appears as a small shining body; anterior hook, about 1μ long; posterior hook most conspicuous, approximately V-shaped, about 3μ long; posterior to these hooks, cuticle armed with about 20 parallel rows of very minute spines encircling anterior portion of larva for a distance of about 16μ from anterior end; spines larger and more prominent on dorsal than on ventral surface (fig. 1, *B*); spines of posterior rows becoming gradually smaller, last row very difficult to see. Tail (fig. 1, *E*) with a row of about 8 to 10 small refringent points encircling tip; these structures were pointed out by Stiles (*131*) in embryonic forms, and this character is diagnostic for first-stage larvae.

Alimentary tract.—Oral opening leading into a transparent esophagus 167μ to 243μ long and extending to a distance of slightly less than one-half of length of worm. Intestine also transparent, apparently composed of about 5 anterior large cells extending about two-thirds of length of intestine, and a posterior group of about 6 cells connecting with a very short rectum (fig. 1, *D*).

Nervous system.—Difficult to determine in living specimens. After larva is stained with aqueous methylene blue, nerve ring appears as a band surrounding posterior third of esophagus, 45μ to 110μ from anterior end, and surrounded by several nuclei of nerve cells.

Excretory system.—Excretory pore, 60μ to 145μ from anterior end, leads into a short dilated excretory duct (fig. 1, *D*); excretory duct opens from a glandular excretory cell possessing a large nucleus.

Genital primordium.—In living specimens hardly distinguishable from large muscle cells of body wall.

Table 1 shows the rate of development of first-stage larvae of *Gongylonema pulchrum* in an intermediate host (*Blatella germanica*),

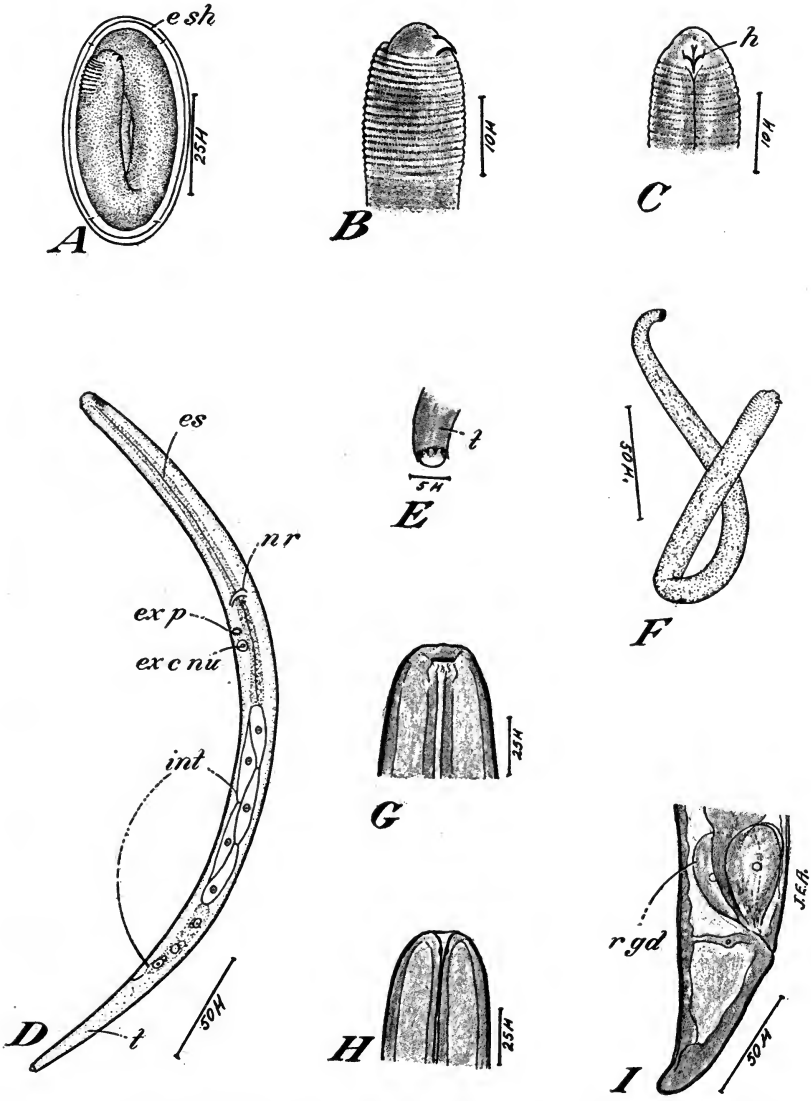

FIGURE 1.—VARIOUS STAGES IN THE DEVELOPMENT OF GONGYLONEMA PULCHRUM.

Embryo: *A*, Fully developed, in egg; *F*, fully developed, obtained by crushing the eggshell.
First-stage larva: *B*, Anterior end, lateral view; *C*, anterior end, ventral view; *D*, larva from intermediate host 4 days after experimental infection; *E*, tail, lateral view.
Second-stage larva: *G*, Anterior end, lateral view; *H*, anterior end, dorsal view; *I*, tail, lateral view.

the measurements having been made on different days after experimental infection.

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TABLE 1.—*Principal measurements of 6 first-stage larvae of Gongylonema pulchrum at various periods of development in the roach*

Item	Period of development and measurements of larva no.—					
	1	2	3	4	5	6
Period of development.....days	1	2	4	4	[1] 19	[1] 19
Length of body.....microns	243	334	372	372	480	540
Maximum width of body.....do	15	15	15	15	34	38
Length of esophagus.....do	-------	167	178	172	190	243
Distance of nerve ring from anterior end.....do	45	-------	60	58	-------	110
Distance of excretory pore from anterior end.....do	60	110	136	133	140	145
Length of tail.....do	49	49	57	53	53	60

[1] Larva undergoing first molt.

SECOND-STAGE LARVA

Shape and size.—Young form similar in shape and size to older larva of first stage. As larva grows, it loses its club-shaped appearance and becomes more or less uniform in width, except for tapering anterior and posterior portions (fig. 2, *C*). Young specimen about 842μ long by 45μ wide; older specimen about 2.01 mm long by 53μ wide (table 2).

Cuticle.—Without armature or hooks at anterior portion and without refringent points encircling tip of tail (fig. 1, *I*); faint transverse striations present.

Alimentary tract.—Oral opening leading into cavity surrounded by poorly developed buccal capsule, 36μ to 38μ long; capsule more distinct in older larva of this stage than in newly molted form; entrance to lumen of buccal cavity surrounded by a thin cuticularized ring, flattened laterally (fig. 1, *G* and *H*). Esophagus well developed, less transparent than that of previous stage, and occupying about one-half of body length; esophagus slender, more or less uniform in width in young larva of this stage, but in older larva becoming differentiated into proesophagus—an anterior, comparatively short slender muscular portion, 53μ to 240μ long—and postesophagus—a posterior and wider glandular portion, 441μ to 1,150μ long; esophagus opening into a long slender intestine composed of many cells having poorly defined walls; posterior portion of intestine opening into a large rectum surrounded by large rectal glands, 2 subventral and 1 dorsal.

Nervous system.—Nerve ring 109μ to 121μ from anterior end, distinctly visible as a band surrounding anterior portion of esophagus (fig. 2, *C*); details of nervous system most evident in late second-stage larva, and very similar to those of third-stage larva.

Excretory system.—As in previous stage. In living specimens, nucleus of excretory cell not so conspicuous as in previous stage, owing to greater thickness of cuticle; excretory pore opening 150μ to 200μ from anterior end.

Genital primordium.—This developing organ best seen in living specimens of older larva of this stage, appearing as a small ellipsoidal body, ventral in position, 53μ to 342μ from tip of tail, the distance depending on size of larva.

Table 2 shows rate of development of second-stage larvae of *Gongylonema pulchrum* in an intermediate host (*Blatella germanica*) the measurements having been made at different days after experimental infection.

TABLE 2.—*Principal measurements of 6 second-stage larvae of Gongylonema pulchrum at various periods of development in the roach*

Item	Period of development and measurements of larva no.—					
	1	2	3	4	5	6
Period of development.....days	19	23	27	27	[1] 29	[1] 32
Length of body.....microns	842	1,045	1,138	1,497	1,900	2,010
Maximum width of body.....do	45	46	53	53	53	53
Length of proesophagus.....do	-------	-------	53	60	220	240
Length of postesophagus.....do	-------	-------	441	780	810	1,150
Total length of esophagus.....do	300	561	494	840	1,030	1,390
Distance of nerve ring from anterior end.....do	-------	-------	-------	109	114	121
Distance of excretory pore from anterior end.....do	150	171	174	-------	152	200
Distance of genital primordium from posterior end.....microns	53	-------	180	-------	342	-------
Length of tail.....do	68	83	88	98	93	106

[1] Larva undergoing second molt.

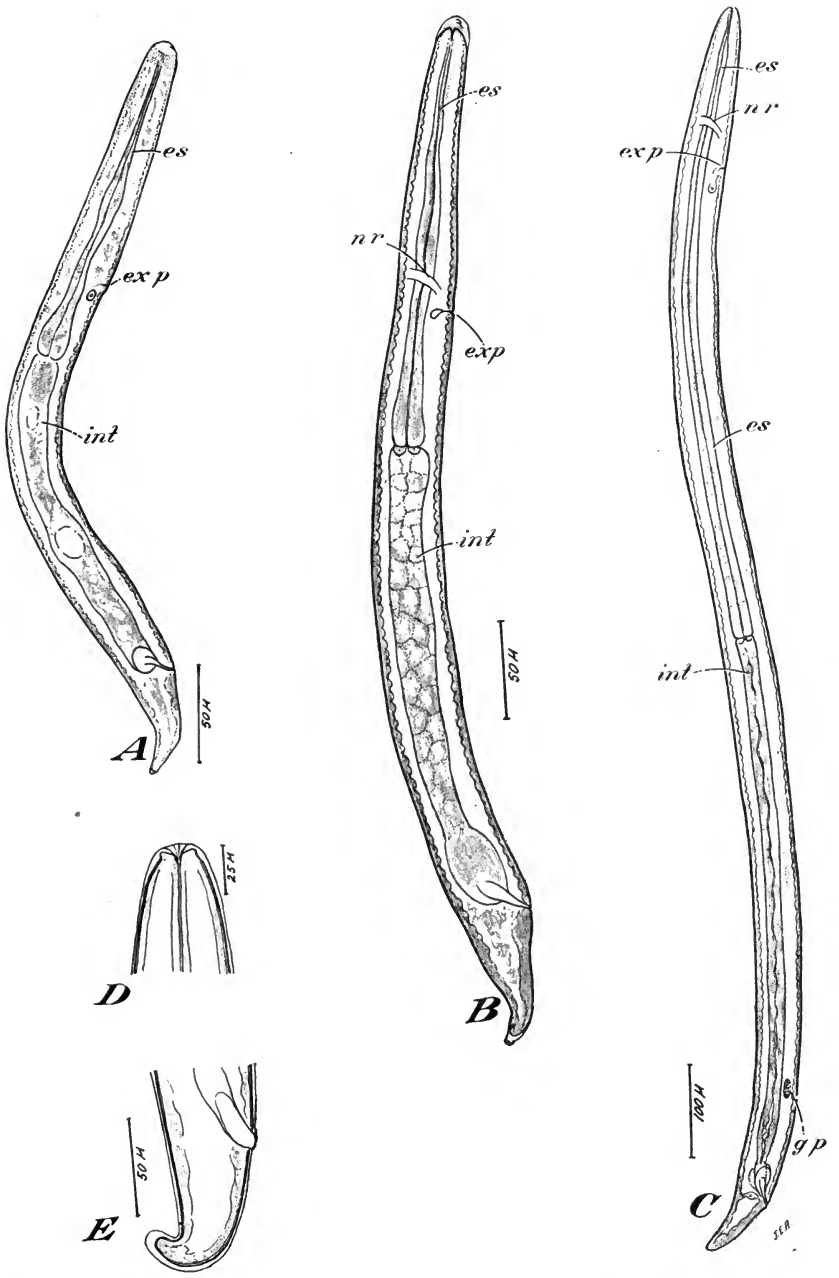

FIGURE 2.—FIRST- AND SECOND-STAGE LARVAE OF GONGYLONEMA PULCHRUM.

First-stage larva: *A*, Lateral view; *B*, undergoing first molt.
Second-stage larva: *C*, Lateral view; *D*, anterior end of larva undergoing second molt; *E*, posterior end of larva undergoing second molt.

THIRD-STAGE LARVA

Shape and size.—Body of larva slender and of same width for most of length, tapering slightly at anterior portion and rather abruptly posterior to anus.

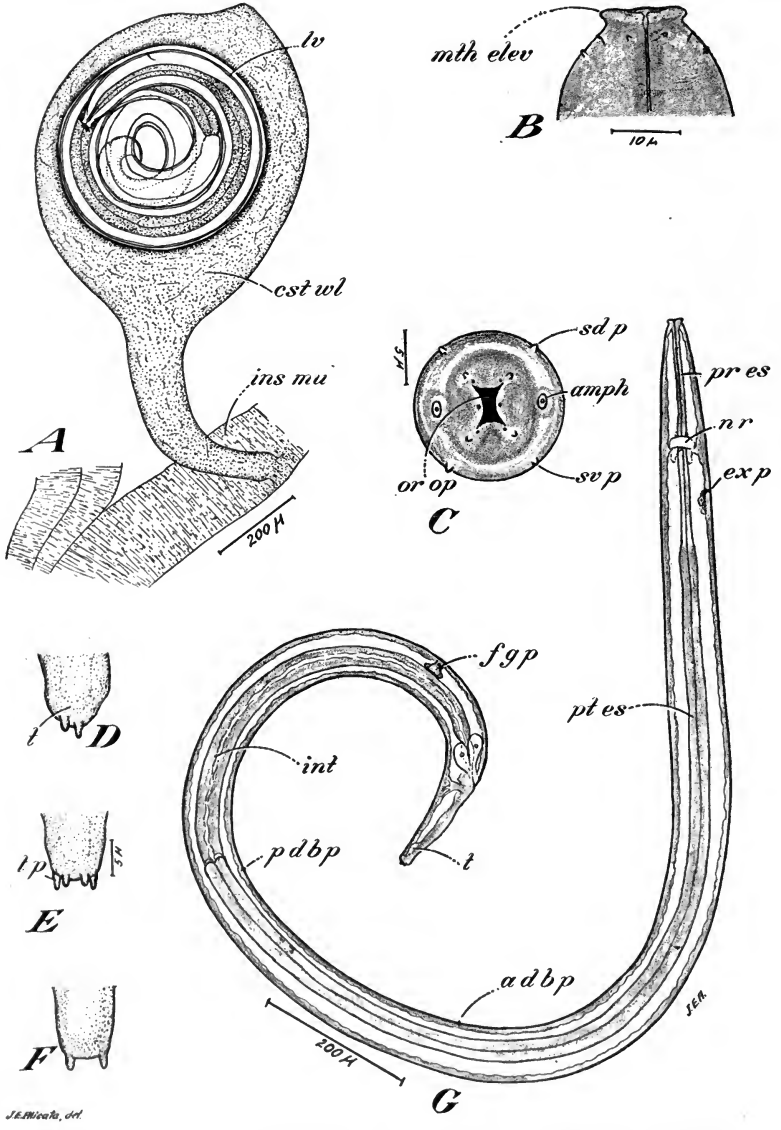

FIGURE 3.—THIRD-STAGE LARVAE OF GONGYLONEMA PULCHRUM.

A, Larva encysted in musculature of a roach (*Blatella germanica*); *B*, anterior end of larva, ventral view; *C*, anterior end, en face view; *D*, posterior end showing digitiform processes, lateral view; *E*, posterior end showing the usual four digitiform processes, ventral view; *F*, posterior end showing digitiform processes; *G*, lateral view of larva.

Lateral border of mouth projecting outward and elevated above surrounding surface of head (fig. 3, *B*); head surrounded by outer circle of 2 subdorsal and 2 subventral papillae and 2 lateral amphids; also an inner circle of smaller papillae, 2 pairs subdorsal, 2 pairs subventral, and 1 pair lateral (fig. 3, *C*); 2 small lateral

cervical papillae (deirids) projecting from cuticle slightly posterior to midway between anterior body extremity and nerve ring; 2 additional papillae on dorsal surface of larva, the anterior one slightly postequatorial and the posterior near region of base of esophagus (figs. 3, *G* and 4, *G*). Tail conical, usually terminating in 4 small digitiform processes, 2 subdorsal and 2 subventral, the subventrals in some specimens scarcely visible or entirely lacking (fig. 3 *D*, *E*, and *F*); visible

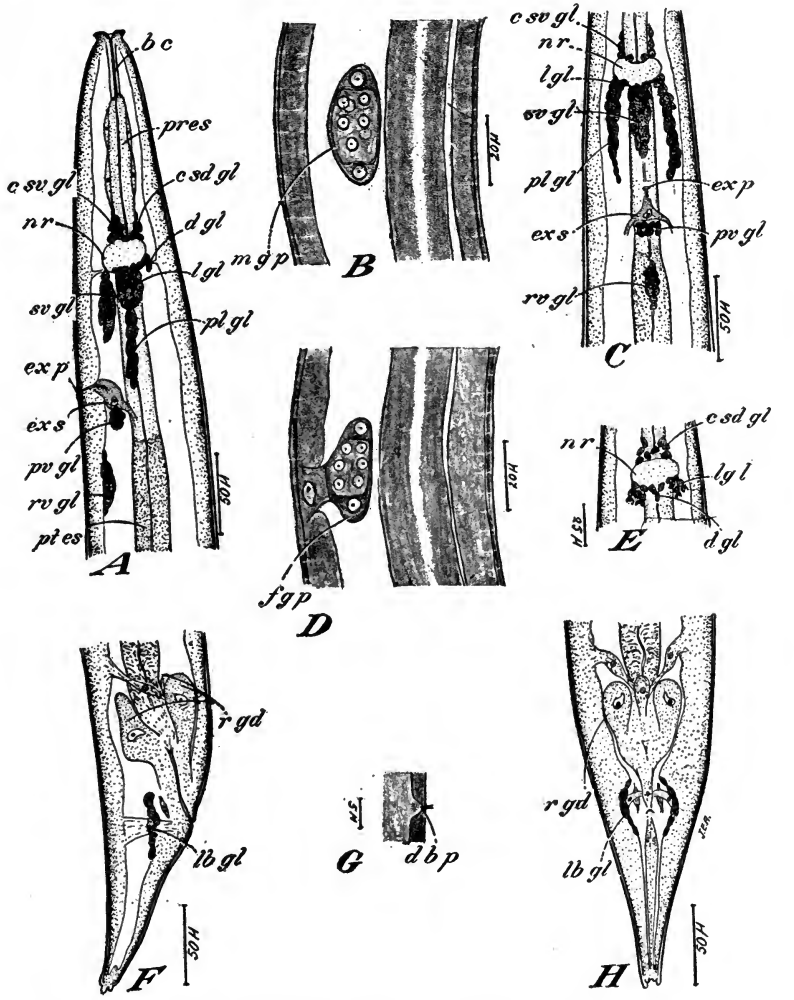

FIGURE 4.—THIRD-STAGE LARVAE OF GONGYLONEMA PULCHRUM.

A, Anterior end, lateral view; *B*, portion of larva showing male genital primordium, lateral view; *C*, anterior portion showing features of nervous system, ventral view; *D*, portion of larva showing female genital primordium attached to body wall, lateral view; *E*, region of nerve ring, dorsal view; *F*, posterior portion of larva, lateral view; *G*, portion of larva showing a dorsal body papilla; *H*, posterior portion of larva, ventral view.

processes about 2μ long. Larvae from 1.9 to 2.45 mm long by 50μ to 68μ wide; according to Seurat (*117*), larvae from 3.4 to 4.2 mm long by 72μ to 77μ wide; according to Ransom and Hall (*99*), larvae 1.9 mm long by 60μ wide.

Cuticle.—With prominent transverse striations.

Alimentary tract.—Oral opening, in en face view, elongated dorsoventrally, rectangular, with concave margins (fig. 3, *C*); aperture leading into a slender mouth cavity. In optical section, walls of mouth cavity appear as two long rods

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differing slightly in length, the dorsal rod about 26μ long and the ventral one about 28μ long; width of these rods, about 2.5μ. Esophagus about three-fourths as long as body, differentiated into a proesophagus, 258μ to 308μ long, and a postesophagus 1.07 to 1.26 mm long. Intestine a short tube occupying about one-fifth of body length, connected posteriorly to rectum. Rectum about 35μ long, surrounded by 3 large rectal glands, 2 subventral and 1 dorsal.

Nervous system.—Readily visible, especially in specimens stained in acid carmine. Nerve ring appears as thick ring encircling esophagus, 114μ to 136μ from anterior end; according to Seurat (*117*), nerve ring 140μ to 160μ, according to Ransom and Hall (*99*), 125μ, from anterior end. Anterior to nerve ring, 4 strands of well-stained nuclei present, probably representing the nuclei of 2 subdorsal and 2 subventral cephalic ganglia (fig. 4, *A*, *C* and *E*); nuclei of cells of the lateral ganglia not observed. Posterior to nerve ring, 2 lateral ganglia, each connected posteriorly to another group of cells, the posterolateral ganglia; dorsally, one nucleus probably representing the cell of the dorsal ganglion; ventrally, the subventral ganglia fused into one large group of cells (fig. 4, *C*). Posterior to excretory sinus, the posteroventral ganglia represented by seven cells of which only the nuclei are visible; slightly posterior to excretory pore, a group of cells forming the retrovesicular ganglia (fig. 4, *A* and *C*) are present; surrounding the anal region and extending posteriad to the rectal glands, a small group of nuclei representing the cells of the lumbar ganglia (fig. 4, *F* and *H*).

Excretory system.—As in previous stage. Excretory pore 190μ to 228μ from anterior end; according to Seurat (*117*), excretory pore 215μ to 250μ according to Ransom and Hall (*99*); 210μ, from anterior end. Excretory duct opening into a triangular excretory sinus possesses a large nucleus in its walls (fig. 4, *C*).

Genital primordium.—As observed by the writer, male genital primordium (fig. 4, *B*) elliptical in shape, 30μ to 34μ long by 10μ to 15μ wide, located on ventral side between body wall and intestine, 345μ to 375μ from posterior end of body, and composed of 2 large epithelial cells enclosing a group of about 6 or 7 nuclei of germinal cells. Female genital primordium (fig. 4, *D*) somewhat elliptical, 30μ long by 10μ wide, attached to ventral side of body wall as noted by Seurat (*118*, *119*); attachment by means of a large cell about 8μ long located 260μ to 275μ from tip of tail. Measurements given in table 3 indicate that the female genital primordium is closer to the posterior end of the larva than is that of the male.

Table 3 shows the measurements of third-stage larvae of *Gongylonema pulchrum* in an intermediate host (*Blatella germanica*).

TABLE 3.—*Principal measurements of 10 third-stage larvae of Gongylonema pulchrum at various periods of development in the roach*

Item	Period of development and measurements of—									
	Male no.—					Female no.—				
	1	2	3	4	5	1	2	3	4	5
Period of development.....days	32	32	38	38	42	32	32	36	38	42
Length of body.....millimeters	1.90	2.08	2.20	2.25	2.27	2.05	2.10	2.28	2.30	2.45
Maximum width of body.....microns	53	53	53	53	53	50	60	64	53	68
Length of buccal cavity.....do	28	26	26	28	28	26	28	28	28	30
Length of proesophagus.....do	265	296	273	281	281	288	258	300	296	308
Length of postesophagus.millimeters	1.07	1.26	1.17	1.12	1.20	1.07	1.09	1.20	1.25	1.26
Distance of nerve ring from anterior end.....microns	114	124	136	------	129	136	130	130	136	136
Distance of excretory pore from anterior end.....microns	190	228	220	215	210	220	228	220	228	220
Distance of cervical papillae from anterior end.....microns	76	80	86	86	90	94	80	86	94	102
Distance of dorsal body papillae from posterior end:										
Anterior papilla.....microns	900	------	1,000	1,080	1,100	1,050	------	------	------	1,092
Posterior papilla.....do	575	------	700	710	780	700	------	------	------	890
Distance of genital primordium from posterior end.....microns	375	375	375	------	345	------	260	280	275	285
Length of tail.....do	98	114	114	114	98	95	114	114	114	106

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DIFFERENCES IN FIRST THREE STAGES

The outstanding differential features of the first three developmental stages of *Gongylonema pulchrum* are as follows:

First-stage larva.—Cuticle at anterior end provided with 1 spine and 2 hooks longitudinally arranged; posterior to these hooks, about 20 parallel rows of very minute spines encircling the cephalic portion; tip of tail blunt, surrounded by a row of small refringent processes.

Second-stage larva.—Cuticle without armature present as in previous stage; anterior and posterior ends bluntly rounded.

Third-stage larva.—Cuticle as in second stage; lateral border of mouth raised above surrounding surface of head and projecting outward; tail provided with 4 small digitiform processes, 2 subventral and 2 subdorsal, the subventral ones frequently only barely visible or entirely lacking.

Development in Intermediate Host

Eggs of *Gongylonema pulchrum* were obtained by chopping up gravid female worms in a few drops of distilled water. This material was then transferred to small pieces of bread and introduced into a 300-cc Erlenmeyer flask in which there were placed about a dozen roaches (*Blatella germanica*). The roaches had been previously starved for about 24 hours. The top of the flask was closed with a layer of cheesecloth. In order to learn the approximate time required for larval development, the roaches were allowed to feed on the infested bread for about 5 hours, after which they were transferred to a clean flask containing food not contaminated with eggs.

Roaches dissected about 24 hours after they had ingested the eggs already had empty eggshells in their crops and intestines, an observation which was reported by Ransom and Hall (*98, v. 2*) in their first extensive paper on the life history of this parasite. At this time there were also found several newly hatched larvae still adhering to the wall of the crop and apparently ready to invade the body cavity of the roach. No larvae were found in the lumen or wall of the intestine, a fact which shows that possibly hatching took place in the crop and that the larvae found their way into the body cavity by piercing the wall of the crop. About 48 hours after ingestion of eggs, first-stage larvae were found in the body cavity of the roach, usually more numerous in the thoracic region than elsewhere. At the end of about 15 days, the wandering larvae had doubled their original size and appeared very plump. At this time the first cuticle had begun to loosen at the anterior and posterior ends (fig. 2, *B*). These observations are in agreement with the findings of Ransom and Hall (*98, v. 2*), who state that these larvae were on the verge of a molt in the intermediate host 2 weeks after experimental infestation. The first molt did not take place, however, until about the nineteenth day, when some larvae are already in the second stage.

The second-stage larvae also wandered in the body cavity, especially in the abdominal region, where they increased considerably in length. In about 27 days the larvae were 1.13 to 1.5 mm long by 53μ wide. At this time they usually penetrated the muscles of the body wall, especially those of the ventral portion of the abdomen. In heavy infestations the larvae may invade the walls of the crop and intestine and the muscles of the coxae. Partial encystment has been observed to precede the second molt. Larvae undergoing the second molt were found 29 to 32 days after experimental infection,

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and larvae which had completed the second molt and were in the third stage were found 32 days after infection. These findings agree with those of Ransom and Hall (*98, v. 2*), who state that at the end of about a month the larvae were encysted, that is, in the final larval stage. The writer's observations are also in agreement with those of Lucker (*68*), who, in dissecting experimentally infested roaches 34 days after infection, found encysted larvae which produced an infestation when fed to pigs.

Encysted *Gongylonema* larvae were studied both by gross dissection and in cross sections of infested roaches. The observations made indicated that each encysted larva was embedded within the sarcoplasm surrounding the muscle fiber. The nuclei in the sarcoplasm surrounding the cyst wall of the larva were very distinct in stained sections (figs. 5 and 6). As the cyst became well formed it was some-

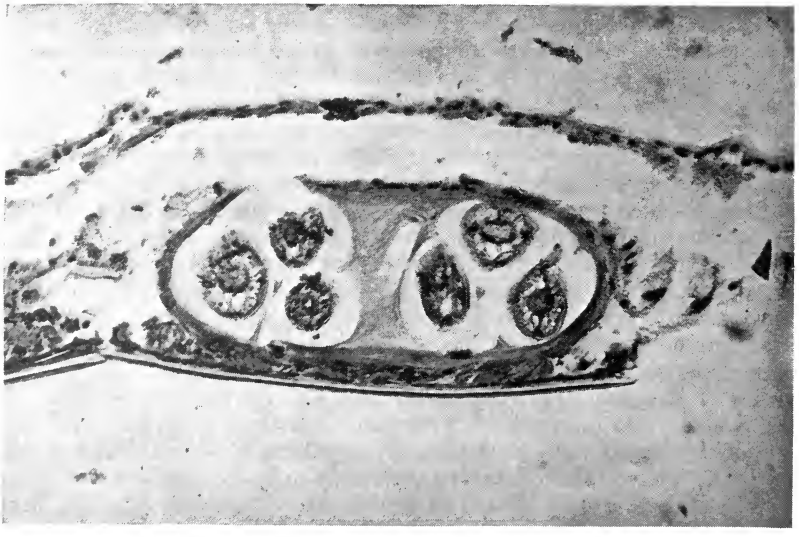

FIGURE 5.—Cross section of a roach (*Blatella germanica*), showing *Gongylonema* larva encysted in the body wall.

times pushed out into the body cavity until its attachment to the muscle was merely by a thin strand (fig. 3, *A*). At this time most of the nuclei in the cyst wall became degenerated, so that in stained sections of these cysts only a few nuclei were visible at the place of the attachment of the cyst. The outer portion of the cyst did not stain well and had the appearance of cloudy degeneration as observed in vertebrate tissue.

DEVELOPMENT IN DEFINITIVE HOST

The study of the third and fourth stages in the definitive host was advantageously carried out in the guinea pig, an experimental animal which can be easily and thoroughly examined post mortem. Though this animal is not a normal host for *Gongylonema*, it is safe to assume that the same mode of larval development and migration takes place in it as in the more usual hosts, namely, cattle, sheep, and swine.

Tables 4 and 5 show the measurements of third- and fourth-stage larvae in different periods of development. As shown in table 4, in 12 days after infection the larvae still in the third stage had practically doubled their length. In a guinea pig killed 9 days after experimental infection, there were found larvae at the beginning of

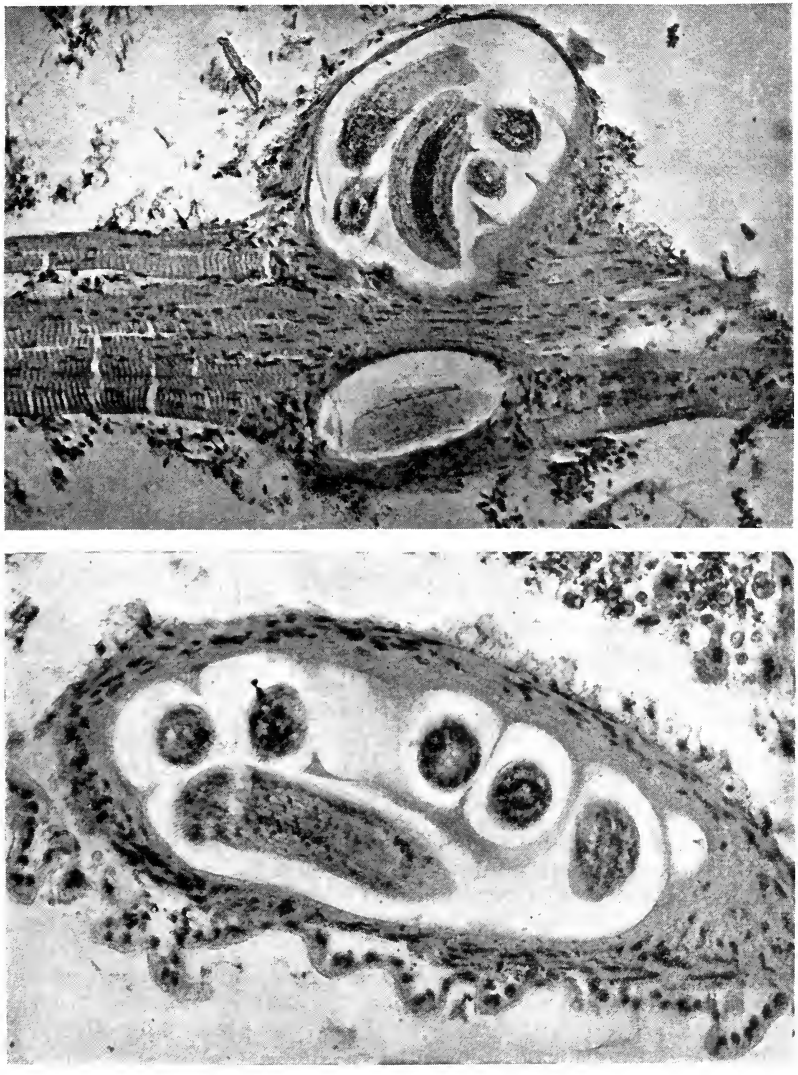

FIGURE 6.—Sections of a roach (*Blatella germanica*) showing *Gongylonema* larva encysted in the musculature.

the third molt (fig. 7, *A–D*). The most outstanding morphological feature of these larvae, as shown in figure 7, is the development of the genital primordium. In the males, the genital system appeared as a slender tube about 550μ long, with its posterior portion about ready to connect with the rectum; in the females, a short ovejector and two divergent uteri were present.

TABLE 4.—*Measurements of 6 third-stage larvae of Gongylonema pulchrum in various periods of development in guinea pigs*

Item	Period of development and measurements of—					
	Male no.—		Female no.—			
	1	2	1	2	3	4
Period of development.....days	3	[1] 9	[2] 8	3	[1] 9	[1] 12
Length of body.....millimeters	2. 80	7. 80	2. 57	2. 58	3. 70	4. 45
Maximum width of body.....microns	76	78	73	70	83	91
Length of buccal cavity.....do	38	38	38	38	38	38
Length of proesophagus.....do	343	312	243	240	326	304
Length of postesophagus.....millimeters	1. 61	1. 78	1. 63	1. 70	1. 87	2. 10
Distance of nerve ring from anterior end.....microns	.....	171	136	148	167	167
Distance of excretory pore from anterior end.....do	.....	.....	235	180	281	304
Distance of cervical papillae from anterior end.....do	.....	.....	106	.....	.....	121
Distance of genital primordium from posterior end.....microns	452	.....	310	.....	421	450
Length of tail.....do	106	156	106	129	152	152

[1] Larva undergoing third molt. [2] Hours.

TABLE 5.—*Measurements of 9 fourth-stage larvae of Gongylonema pulchrum in various periods of development in guinea pigs*

Item	Period of development and measurements of—								
	Male no.—				Female no.—				
	1	2	3	4	1	2	3	4	5
Period of development.....days	12	16	[1] 27	[1] 31	12	16	27	[1] 27	[1] 31
Length of body.....millimeters	4. 60	7. 70	11. 00	12. 00	5. 85	8. 90	15. 50	18. 00	20. 00
Maximum width of body.....microns	.....	90	90	121	90	114	121	121	156
Length of buccal cavity.....do	38	45	45	45	38	42	45	53	45
Length of proesophagus.....do	265	.....	364	402	380	360	402	487	456
Length of postesophagus.....millimeters	1. 76	.....	2. 40	2. 55	2. 48	2. 40	2. 65	3. 36	3. 00
Distance of nerve ring from anterior end.....microns	152	174	184	220	180	205	197	281	266
Distance of excretory pore from anterior end.....microns	258	.....	334	364	349	.....	387	440	468
Distance of cervical papillae from anterior end.....microns	115	120	.....	136	118	.....	136	144	156
Distance of dorsal body papillae from posterior end:									
Anterior papilla.....millimeters	2. 75	4. 80	6. 20	.....	3. 10	5. 30	10. 8	.....	.....
Posterior papilla.....do	1. 60	2. 60	3. 98	.....	2. 25	3. 40	5. 3	.....	.....
Distance of vulva region from posterior end.....microns	.....	.....	.....	.....	546	826	1, 170	1, 200	1, 200
Length of tail.....do	121	167	178	.....	144	159	179	167	182

[1] Larva undergoing fourth molt.

In a guinea pig killed 12 days after infection, some larvae already in the fourth stage were found. Measurements of these larvae are given in table 5. The outstanding features of this stage are the following: The anterior end of the larvae retains to some extent lateral and outward directed elevations (fig. 7, *F* and *G*) similar to those present in the previous stage. The cuticle in young fourth-stage larvae does not show bosses on the anterior portion, but these structures are gradually formed as the larvae grow older (fig. 7, *H*). In males, the posterior portion of the vas deferens is already connected with the rectum, and at the time of the fourth molt males have well-developed spicules and caudal papillae have formed (fig. 7, *J*). The females have a long ovejector with one uterus extending anteriorly and the other posteriorly (fig. 7, *L*). The tails of both sexes at this stage are rounded and lack the digitiform appendages found in larvae of the previous stage. Fourth-stage larvae grow considerably in length, the males apparently not growing so long as the females. In 27 to 31 days after infection, the males are 11 to 12 mm long,

whereas the females are 18 to 20 mm long. At this time both males and females undergo the fourth or last molt, and this cuticle is not actually cast off until 37 days after infection. The fifth stage, which represents adult forms, is easily differentiated from the previous

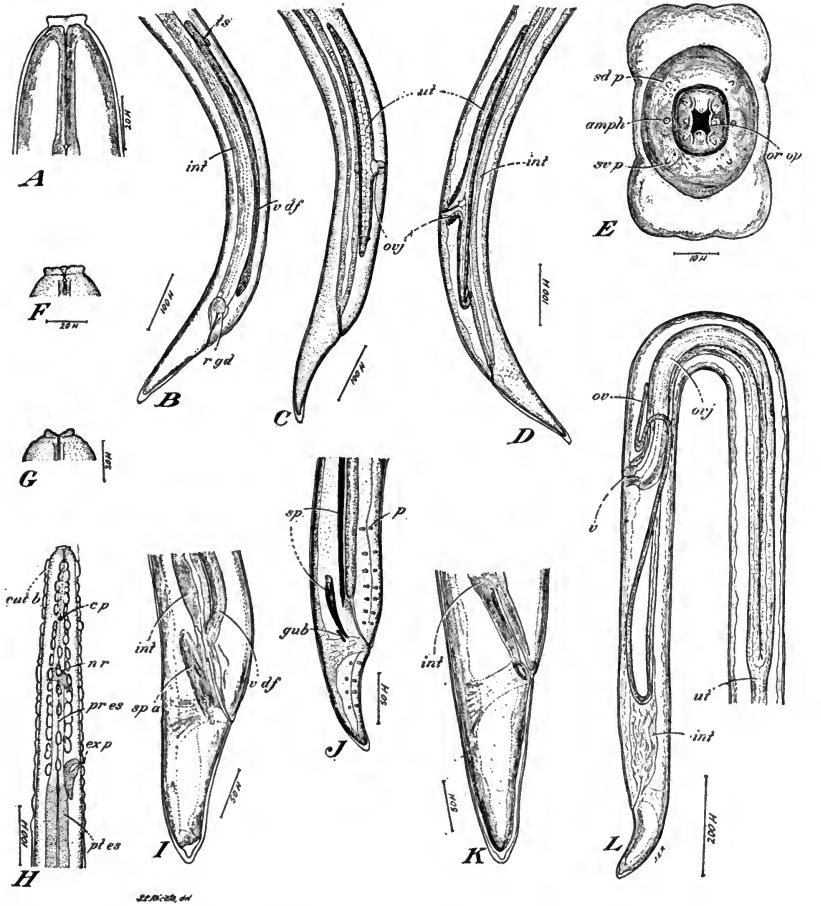

FIGURE 7.—THIRD- AND FOURTH-STAGE LARVAE OF GONGYLONEMA PULCHRUM.

Third-stage larva: *A*, Anterior end, undergoing third molt; *B*, posterior portion of male undergoing third molt; *C*, *D*, posterior portion of female undergoing third molt.

Fourth-stage larva: *E*, Anterior end, en face view; *F*, anterior end, lateral view; *G*, anterior end, ventral view; *H*, anterior portion; *I*, posterior portion of male on verge of fourth molt; *J*, posterior portion of male in fourth molt; *K*, posterior portion of larva in fourth molt; *L*, region of vulva of larva undergoing fourth molt.

stage; the females have the vulva opening to the outside and the male's caudal alae have several preanal and postanal papillae.

After the last molt, these worms grow considerably. One adult male worm obtained from the esophagus of a guinea pig 70 days after experimental infection had the following measurements; Length, 32 mm; maximum width, 140μ; length of proesophagus and postesophagus, 577μ and 4.5 mm, respectively; length of right and left spicules, 121μ and 8.5 mm, respectively. Two young adult female

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worms just beginning oviposition, also obtained from the esophagus of the guinea pig referred to above, had the following measurements: Length, 55 and 60 mm; maximum width, 235μ; length of proesophagus,

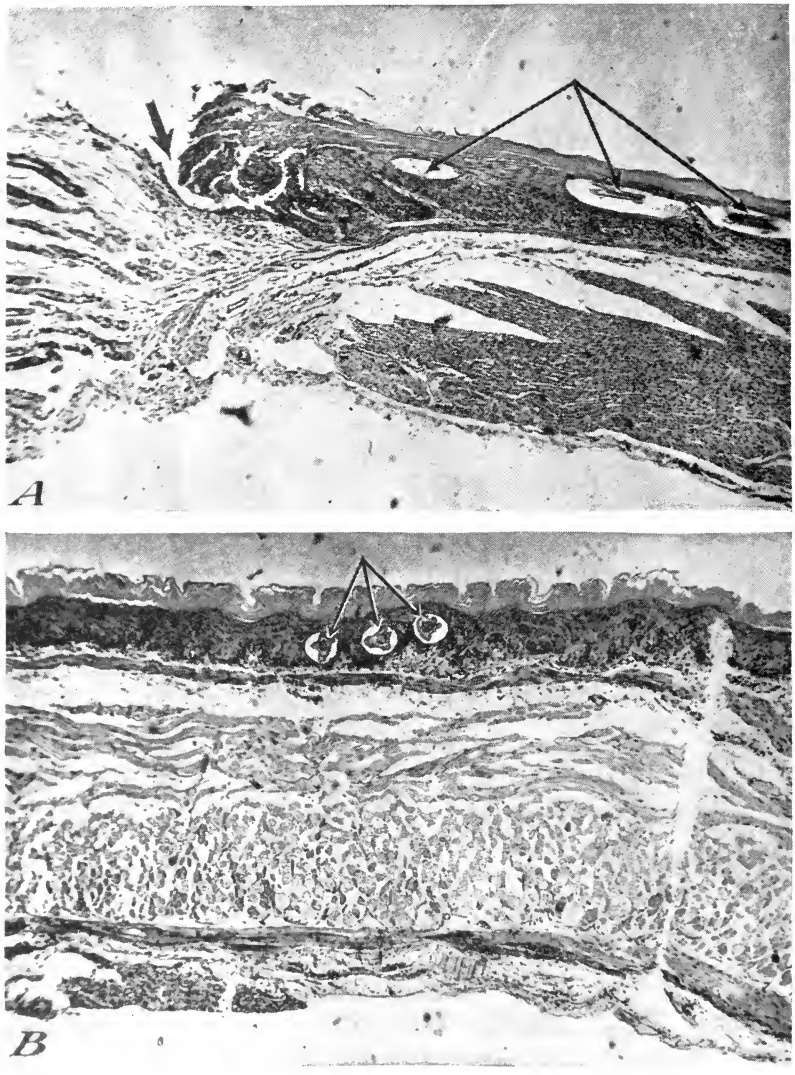

FIGURE 8.—*A*, Longitudinal section of gastroesophageal junction of a guinea pig 18 hours after experimental infection with larvae of *Gongylonema pulchrum*, showing larvae embedded in epithelium of esophagus. Large arrow points out the possible mode of entrance of the larvae into the esophagus; *B*, cross section of esophagus of a guinea pig 18 hours after experimental infection showing a larva embedded in the epithelium.

655μ and 672μ; length of postesophagus, 5 and 5.2 mm; length of tail, 280μ and 292μ.

MIGRATION OF LARVAE IN DEFINITIVE HOST

During the month of April 1933, encysted third-stage larvae of *Gongylonema pulchrum*, obtained from experimentally infected

cockroaches, were fed with the aid of a pipette to five guinea pigs weighing from 135 to 150 g. These guinea pigs were kept without food for about 24 hours before the infective larvae were fed. A description of these tests and the results are as follows:

Guinea pig 1 was given 9 infective larvae and was killed one-half hour later. The tongue, esophagus, and stomach were then dissected and removed from the body. The stomach was opened and washed in a Petri dish containing physiologic saline solution. Most of the stomach was cut into pieces about 2 cm square, and each piece was pressed between two glass slides and examined with the aid of a binocular microscope. The esophagus, together with a portion of the anterior part of the stomach, was examined as a whole. Press preparations were also made of the tongue, palate, and oral linings. By this method larvae were easily detected whenever they were present. Seven larvae were recovered from this guinea pig, 2 larvae being embedded in the esophageal wall about 2 mm from the gastroesophageal junction, 1 larva in the cardiac portion of the stomach wall, and 4 excysted larvae in the stomach contents. The other 2 larvae which had been fed were not found.

Guinea pig 2 was fed 12 infective larvae and was killed 1 hour later. Most of the larvae were found at the junction between the stomach and esophagus, 1 larva in the esophageal wall slightly above this junction, and 2 in the wall of the esophagus about 2 mm from the junction. No larvae were found in the stomach wall or its contents or in the tongue or oral lining. The other larvae which had been fed to the guinea pig were not found.

Guinea pig 3 was fed 12 infective larvae and was killed 18 hours later. Six larvae were found embedded in the wall of the esophagus, scattered about 1 to 3 mm from the gastroesophageal junction, and 1 larva was found about 2 cm from this junction. No larvae were found in the stomach wall or its contents. The esophagus was sectioned (fig. 8) at the points where embedded larvae were found. Figure 8, *A*, shows a larva embedded in the epithelium of the esophagus not far from the gastroesophageal junction, and figure 8, *B*, shows a larva also in the epithelium of the esophagus; the latter larva was located about 2 cm from the base of the esophagus of the guinea pig. The other larvae which had been fed to the guinea pig were not found.

Guinea pig 4 was fed 45 infective larvae and was killed 3 days later. Three larvae were found about 3 cm from the base of the esophagus, and 5 larvae in the posterior portion of the tongue; other larvae were probably present in this region, but were not sought for as the writer was concerned only with the portions of tissues infested. No larvae were found in the stomach wall or its contents.

Guinea pig 5 was fed 45 infective larvae and was killed 10 days later. Two larvae were found 4 cm from the base of the esophagus, several larvae in the walls and lateral portions of the tongue, and 1 larva in the wall of the hard palate. No larvae were found in the stomach or its contents.

These observations indicate that encysted larvae of *Gongylonema pulchrum* excyst in the stomach of guinea pigs and may invade the esophagus within one-half hour after feeding. The observations suggest also that the path of entry of these larvae to the esophagus is through the tissue at the junction of the stomach and esophagus, as the larvae are usually most numerous in that area. This may be

due to a lack of resistance of this tissue or to a chemotaxis or other tropism. In figure 8, *A*, the large arrow points out the possible mode of entrance of the larvae into the esophagus. Larvae may migrate to the esophagus also by first entering the wall of the stomach, but this possibility is apparently rare as in only 1 out of 5 feedings was even 1 larva found in the stomach wall.

After the larvae have penetrated the esophagus, they migrate upward and invade the walls of the oral cavity 3 days after experimental feeding. These larvae may migrate promptly to any part of the walls of the tongue (fig. 9), palate, or lining of the buccal cavity. In observations other than the ones given, larvae have been found to develop to maturity in any of the tissues which have been mentioned as being invaded. It is of interest to note that the wandering larvae are found only in the epithelium of the structures invaded (figs. 8 and

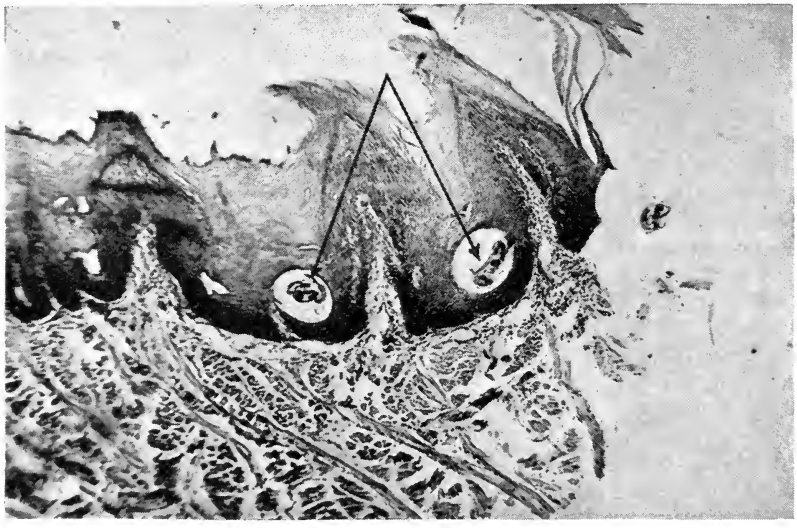

FIGURE 9.—Section of tongue of a guinea pig showing *Gongylonema pulchrum* larvae embedded in the epithelium, 31 days after experimental infection.

9). No extensive lesions have been found associated with infestations with these larvae. This is in agreement with the opinion of Ransom and Hall *(98, v. 2)* who, in comparing this worm with *Gongylonema neoplasticum* (described by Fibiger and Ditlevsen *(25)*, in 1914, as inducing the production of neoplastic changes in stomachs of rats) state that *G. scutatum* (=*G. pulchrum*) can be regarded as probably an innocuous parasite.

Observations on Effects of Environment

Resistance of Eggs to Low Temperatures

On February 17, 1933, several thousand eggs of *Gongylonema pulchrum* were mixed with sterile sand and transferred to 3 small glass tubes about 5 cm high and 8 cm in diameter. Enough water was added to this mixture to give the sand a moist appearance. These tubes were plugged with cotton and placed in two 1-pint fruit

jars, 2 tubes being put in 1 jar and 1 in another jar; the tubes were held straight on the bottom of the jar by fitting absorbent cotton around the tubes. In order to prevent drying of the sand, water was added to the jars to a height of about 3 cm. The jars were then covered with moist paper hand towels and a few holes were made at the top of the paper with the aid of a dissecting needle. The jar containing two tubes was placed outdoors (Washington, D. C.) under shelter so as to prevent rain or snow from falling upon it. On June 17, 1933, 4 months later, one tube was removed from the jar. Some of the eggs were examined and found to contain viable embryos. The eggs were then separated from the sand with the aid of a screen, placed on a piece of bread, and fed to six roaches. About 40 days later the roaches were examined, and all were found to contain *Gongylonema* larvae encysted in the body cavity.

Data in connection with the outside temperatures [3] during the 4 months' exposure of the eggs are as follows: Minimum, −6.6° C.; maximum, 37.7°; total time during which temperature was 0° or lower, 66 hours, and from 1 to 10°, 1,002 hours. The eggs were thus kept in cold and sometimes freezing temperatures 37 percent of the entire period of outdoor exposure without being killed.

LONGEVITY OF EGGS AT ROOM TEMPERATURE

The jar containing one tube was kept indoors at a temperature of from 22° to 24° C. The tube was examined in 4 months and was found to contain eggs with viable embryos. The eggs were separated from the sand and fed to six roaches in the same manner as in the experiment previously described. The roaches were examined 40 days later and were found to contain encysted *Gongylonema* larvae.

ASCAROPS STRONGYLINA (RUDOLPHI, 1819) ALICATA AND McINTOSH, 1933

(Figs. 10–11)

Synonyms.—*Spiroptera strongylina* Rudolphi, 1819; *S. strongyliformis* de Blainville, 1828; *Filaria strongylina* (Rudolphi, 1819) Schneider, 1866; *Arduenna strongylina* (Rudolphi, 1819) Railliet and Henry, 1911; *Habronema strongylina* (Rudolphi, 1819) Ostertag, 1932.

Hosts.—Definitive: Swine, rabbit, wild boar, cattle, guinea pig. Intermediate: Coleoptera (*Aphodius rufus, A. castaneus, Gymnopleurus* sp., *Scarabaeus* sp.) and Odonata (*Anax parthenope*). Accidental: Mammals, birds, and reptiles for third-stage larvae; Alicata and McIntosh (*9*) have found these larvae encysted in the stomachs of bats captured in Washington, D. C.

In addition to the above intermediate hosts, the following insects have been found by the present writer to serve as intermediate hosts for *A. strongylina: Passalus cornutus* and *Aphodius granarius*

Location.—Adults in stomach of definitive host; third-stage larvae in body cavity of intermediate host, and wall of intestine or mesentery of accidental host.

Distribution.—Africa (Algeria), Asia (Cochin China, India, Philippines, Turkestan), Australia, Europe (France, Germany, Hungary, Italy, Rumania), Central America (Nicaragua, Panama), North America (United States), South America (Argentina).

DESCRIPTION OF EGG, EMBRYO, AND LARVAL STAGES

EGG

Egg somewhat elliptical in shape, slightly flattened at each pole (fig. 10, *A*); shell about 2μ thick, with numerous small punctations on surface; under high-

[3] Temperature records obtained from the U. S. Weather Bureau in the District of Columbia.

power magnification each pole with a small pluglike thickening. In a series of measurements involving about 50 eggs, length 41μ to 45μ, width 22μ to 26μ;

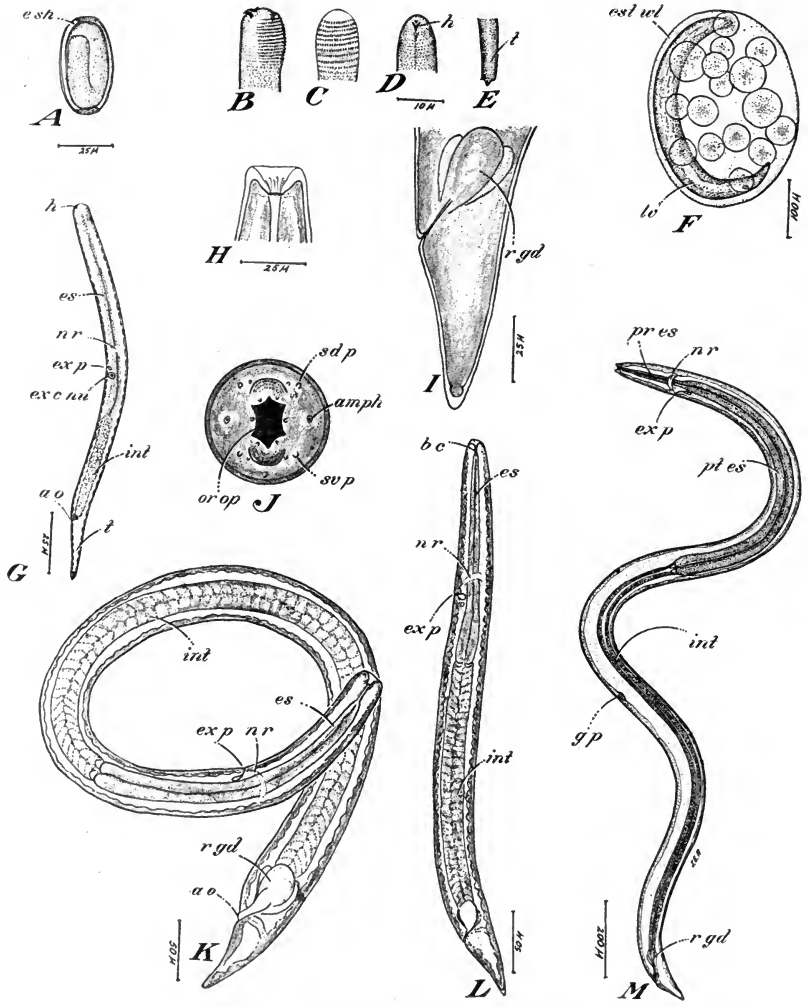

FIGURE 10.—VARIOUS STAGES IN THE DEVELOPMENT OF ASCAROPS STRONGYLINA.

A, Egg, containing fully developed embryo.
First-stage larva: *B*, Anterior end, lateral view; *C*, anterior end, dorsal view; *D*, anterior end, ventral view; *E*, tail; *F*, encysted larva; *G*, larva recovered from an intermediate host 3 days after experimental infection; *L*, larva undergoing first molt.
Second-stage larva: *H*, Anterior end of larva undergoing second molt, lateral view; *I*, posterior end of larva undergoing second molt, lateral view; *K*, lateral view of larva.
Third-stage larva: *J*, Anterior end, en face view; *M*, lateral view of larva.

according to Foster (*26*), length 34μ to 39μ, width 20μ. Each egg contains a well-developed embryo at time of oviposition.

EMBRYO

Embryos, obtained by crushing several eggs on a slide under a cover slip, 110μ to 115μ long by 7.5μ in maximum width. Embryo does not undergo further development before being ingested by intermediate host. Morphology of embryo corresponds to that of young first-stage larva.

FIRST-STAGE LARVA

Shape and size.—Newly hatched larva slender and of same width for most of length (fig. 10, *G*). As it grows during this stage, posterior half of body grows more in width than does anterior half, giving larva a club-shaped appearance. Anterior end broad and rounded, posterior portion tapering slightly; tip of tail ending in characteristic short conical structure about 1.5μ long (fig. 10, *E*). Size of larva depends on degree of development (table 6); before molting, first-stage larva sometimes attains a length of 530μ and a width of 35μ.

Cuticle.—Very thin, transparent, and with very fine transverse striations; ventral portion of anterior extremity with two hooks of different sizes, arranged longitudinally (fig. 10, *D*). When viewed with oil-immersion lens, the most anterior hook appears very minute; posterior hook most conspicuous, approximately V-shaped, about 1.7μ long; posterior to these hooks, cuticle armed with about 17 parallel rows of very minute spines encircling anterior portion of larva for a distance of about 16μ from anterior end; spines larger and more prominent on dorsal than on ventral surface (fig. 10, *B*, *C*, and *D*); spines of posterior rows becoming gradually smaller, the last row being very difficult to see.

Alimentary tract.—Oral opening leading into a long, transparent esophagus 80μ to 190μ in length and extending about one-half of length of worm, length of esophagus depending on degree of development in intermediate host. Intestine transparent, apparently composed of many cells; intestine connecting posteriorly with a very short rectum surrounded by three rectal glands.

Nervous system.—Difficult to determine in living specimens. In larva stained with aqueous methylene blue, nerve ring shows as a band encircling esophagus, 50μ to 75μ from anterior end, and surrounded by several nuclei of nerve cells.

Excretory system.—Excretory pore 60μ to 95μ from anterior end, leading into a short dilated duct, this duct opening into a large excretory cell possessing a large nucleus (fig. 10, *G* and *L*).

Genital primordium.—Hardly distinguishable from large muscle cells of body wall.

Table 6 shows the rate of development of first-stage larvae of *Ascarops strongylina* in an intermediate host (*Aphodius granarius*), the measurements having been made on different days after experimental infection.

TABLE 6.—*Principal measurements of 5 first-stage larvae of Ascarops strongylina at various periods of development in dung beetles*

Item	Period of development and measurements of larva no.—				
	1	2	3	4	5
Period of development.....days	3	4	4	10	[1] 17
Length of body.....microns	158	160	160	163	530
Maximum width of body.....do	9	9	9	10	35
Length of esophagus.....do	80	95	85	88	190
Distance of nerve ring from anterior end.....do	50	50	55	55	75
Distance of excretory pore from anterior end.....do	60	68	70	72	95
Length of tail.....do	26	26	30	30	49

[1] Larva undergoing first molt.

SECOND-STAGE LARVA

Shape and size.—Young form similar in shape and size to older larva of first stage. As larva grows, it loses its club-shaped appearance and becomes more or less uniform in width, except for tapering anterior and posterior portions (fig. 10, *K*). Tip of tail rounded, having lost the conical structure with shedding of first cuticle. These specimens about 720μ to 1,650μ long by 41μ to 62μ wide, depending on degree of development (table 7).

Cuticle.—Without armature in anterior portion; faint transverse striations present.

Alimentary tract.—Oral opening leading into a buccal capsule 35μ to 38μ long; capsule more distinct in older larva of this stage than in newly molted forms. Esophagus slender, 210μ to 436μ long, occupying about one-third of body length,

more or less uniform in width in young larva of this stage, but in older ones becoming differentiated into proesophagus—an anterior, comparatively short slender portion—and postesophagus—a posterior, wide portion about five times as long as proesophagus; esophagus opening into a long slender intestine composed of many cells having poorly defined walls; posterior portion of intestine opening into a large rectum surrounded by large rectal glands, 2 subventral and 1 dorsal in position.

Nervous system.—Nerve ring 80μ to 144μ from anterior end; details of nervous system most evident in late second-stage larvae and very similar to those of third-stage larvae.

Excretory system.—Structure as in previous stage; opening of excretory pore 80μ to 167μ from anterior end of body.

Genital primordium.—Small ellipsoidal body, ventral in position, 362μ to 530μ from tip of tail, the distance depending on size of larva; best seen in living specimens of older larva of this stage.

Table 7 shows the rate of development of second-stage larvae of *Ascarops strongylina* in the intermediate host (*Aphodius granarius*), the measurements having been made on different days after experimental infection.

TABLE 7.—*Principal measurements of 7 second-stage larvae of Ascarops strongylina at various periods of development in dung beetles*

Item	Period of development and measurements of larva no.—						
	1	2	3	4	5	6	7
Period of development.....days	19	19	19	22	22	[1] 28	[1] 28
Length of body.....microns	720	725	920	1,310	1,328	1,375	1,650
Maximum width of body.....do	41	41	45	53	55	55	62
Length of buccal cavity.....do	----	----	----	35	35	35	38
Length of esophagus.....do	240	210	245	380	400	395	436
Distance of nerve ring from anterior end microns	102	80	110	----	120	110	144
Distance of excretory pore from anterior end microns	102	80	110	125	130	120	167
Distance of genital primordium from posterior end.....microns	----	----	----	----	362	400	530
Length of tail.....do	57	57	60	68	83	60	83

[1] Larva undergoing second molt.

THIRD-STAGE LARVA

Shape and size.—Body slender, of same width for most of its length, tapering slightly anteriorly and rather abruptly posterior to anus (fig. 10, *M*); anterior end with characteristic dorsoventral liplike elevations (fig. 11, *C*). Head surrounded by outer circle of 2 large and 2 smaller subdorsal papillae, with corresponding subventral papillae; 2 lateral amphids present; an inner circle of smaller papillae, 1 pair subdorsal, 1 pair subventral, and 1 pair lateral (fig. 10, *J*); 2 small lateral asymmetrical cervical papillae (deirids) present; papilla on right and left sides, 159μ to 195μ and 91μ to 132μ from anterior end, respectively. Tail conical, terminating in a characteristic small smooth knob 7μ to 8μ long (fig. 11, *G*). Larvae 1.91 to 2.32 mm long by 53μ to 91μ wide; according to Seurat (*117*), 1.9 mm long by 80μ wide.

Cuticle.—With prominent transverse striations.

Alimentary tract.—In en face view, oral opening is somewhat hexagonal and elongated dorsoventrally, the aperture leading into a slender mouth cavity. In optical section, walls of mouth cavity appear as 2 rods, each 53μ to 70μ long. Esophagus about one-third as long as body, differentiated into a proesophagus 114μ to 200μ long, and a posteosphagus 590μ to 800μ long. Intestine about two-thirds as long as body, connected posteriorly with rectum. Rectum 30μ to 40μ long, surrounded by 3 large rectal glands, 2 subventral and 1 dorsal in position.

Nervous system.—Readily visible, especially in specimens stained in acid carmine. Nerve ring appears as a thick ring encircling the esophagus 129μ to 152μ from anterior end; according to Seurat (*117*), 154μ from anterior end. General

structure of nervous system (fig. 11, *C*, *E*, *F*, *G*, *H*), similar to that of third-stage larvae of *Gongylonema pulchrum*, except that in *Ascarops strongylina* the cells of subventral ganglia, ventral and posterior to nerve ring, are divided into two groups.

Excretory system.—In general, as in previous stages. Excretory pore 150μ to 205μ from anterior end, its duct opening into a triangular excretory sinus, the sinus wall possessing a single large nucleus.

Genital primordium.—As in *Gongylonema pulchrum*, sex can be differentiated at this stage. Male genital primordium (fig. 11, *B*) 15μ to 18μ long by 9μ to 11μ

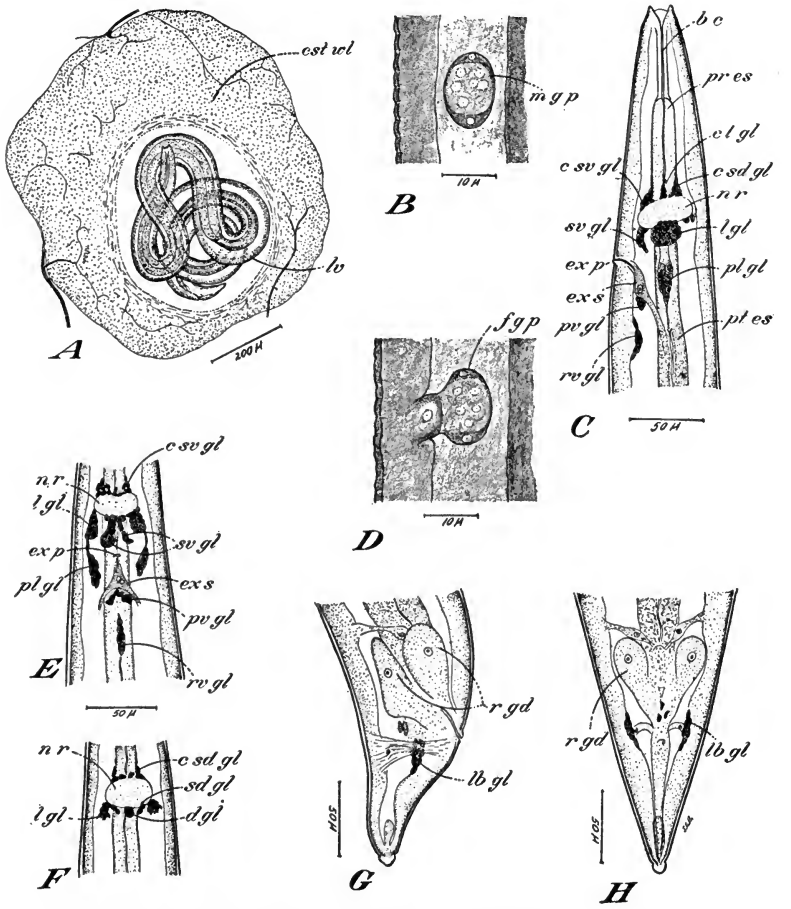

FIGURE 11.—THIRD-STAGE LARVAE OF ASCAROPS STRONGYLINA.

A, Encysted larva; *B*, portion of larva showing the male genital primordium; *C*, anterior portion of larva, lateral view; *D*, portion showing the female genital primordium attached to body wall, lateral view; *E*, anterior portion of larva showing features of nervous system, ventral view; *F*, region of nerve ring, dorsal view; *G*, posterior portion of larva, lateral view; *H*, posterior portion, ventral view.

wide, located ventrally between body wall and intestine, 600μ to 750μ from posterior end of body, composed of 2 large epithelial cap cells enclosing about 7 germinal cells. Female genital primordium also elliptical, 15μ to 18μ long by 9μ to 11μ wide, attached to body wall on ventral side by means of a large cell (fig. 11, *D*) 700μ to 835μ from tip of tail.

Table 8 shows the measurements of third-stage larvae of *Ascarops strongylina* in an intermediate host (*Aphodius granarius*).

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TABLE 8.—*Principal measurements of 9 third-stage larvae of Ascarops strongylina at various periods of development in dung beetles*

Item	Period of development and measurements of larvae								
	Male no.—					Female no.—			
	1	2	3	4	5	1	2	3	4
Period of development—days	29	29	35	35	40	35	35	40	40
Length of body—millimeters	1.91	1.97	2.11	2.20	2.30	1.97	2.00	2.30	2.32
Maximum width of body—microns	55	60	65	72	83	53	60	76	91
Length of buccal cavity—do	53	53	60	64	60	45	------	60	70
Length of proesophagus—do	182	114	179	125	200	171	165	133	174
Length of postesophagus—do	590	690	600	710	296	690	690	760	800
Distance of nerve ring from anterior end—do	129	136	144	144	152	144	136	144	152
Distance of excretory pore from anterior end—microns	182	190	190	195	205	150	159	159	205
Distance of cervical papillae from anterior end:									
Right papilla—microns	182	180	------	175	190	------	159	170	195
Left papilla—do	95	106	------	106	126	------	91	106	132
Distance of genital primordium from posterior end—microns	670	600	750	700	700	700	700	820	835
Length of tail—do	83	76	96	87	83	76	91	83	83

DIFFERENCES IN FIRST THREE STAGES

The outstanding differential features of the first three developmental stages of *Ascarops strongylina* are as follows:

First-stage larva.—Cuticle at anterior end apparently provided with 2 longitudinally arranged hooks; posterior to these hooks, about 17 parallel rows of very minute spines encircling the cephalic portion of larva; tip of tail conical.

Second-stage larva.—Cuticle without such armature as in previous stage; anterior and posterior ends bluntly rounded.

Third-stage larva.—Cuticle as in second-stage larva; anterior end with 2 dorsoventral elevations; tip of tail possessing a smooth knoblike process.

DEVELOPMENT IN INTERMEDIATE HOST

Eggs of *Ascarops strongylina* were obtained by chopping up gravid female worms in a few drops of distilled water. This material was transferred to small pieces of blotting paper and introduced into small glass tubes about 2 cm in diameter and 5 cm in height. In each of these tubes, there were placed six dung beetles (*Aphodius granarius*). The beetles had been collected from sheep manure, and when many of them were dissected previous to infection none were found to harbor a natural infestation with *Ascarops strongylina*. Glass tubes containing eggs and beetles were kept outdoors under shelter.

Beetles (*Aphodius granarius*), dissected 24 hours after they had been exposed to infective eggs, contained a few first-stage larvae in the abdominal portion of the body cavity. Young larvae, 1 to 2 days after infection, were 158μ to 160μ long by 9μ wide. About 15 days after infection, most first-stage larvae were found encysted in the walls of the Malpighian tubules. These cysts were usually spherical and thin-walled, and, besides the larva, a cyst contained several rounded bodies, possibly fat cells (fig. 10, *F*). At the end of about 17 days, several larvae were noted undergoing the first molt (fig. 10, *L*), and 2 days later several larvae were already in the second stage. Larvae undergoing the second molt (fig. 10, *H*, *I*) were found 28 days after experimental infection, and third-stage larvae

were found in beetles dissected 1 day later. During the development of the larva the cyst increased in size, being about 524μ to 936μ in its greater diameter and 420μ to 700μ in its lesser diameter when fully developed. Completely formed cysts were usually found free in the abdominal portion of the body cavity of the beetle, frequently being interlaced superficially by small tracheal tubules of the insect (fig. 11, *A*).

Observations on Effects of Environment

RESISTANCE OF EGGS TO LOW TEMPERATURES

On February 17, 1933, about 1,000 eggs of *Ascarops strongylina* were mixed with sterile sand, and the mixture was placed in two small glass tubes. Enough water was added to this mixture to give the sand a moist appearance. These tubes were plugged with cotton and placed in a refrigerator. On March 9, 20 days later, the tubes were removed from the refrigerator. The eggs were separated from the sand, placed on pieces of blotting paper, and the blotting paper and eggs put in a tube containing several dung beetles (*Aphodius granarius*). These beetles were examined at intervals of from 10 to 20 days after their exposure to infestation, and each was found to contain several young larvae of *Ascarops strongylina*.

The temperature range during the 20 days' exposure in the refrigerator was as follows: Minimum, —4° C.; maximum, 2°. The total time during which the temperature was 2° was 48 hours; 1°, 24 hours; 0°, 48 hours; —1°, 24 hours; —2°, 216 hours; —3°, 24 hours; —4°, 76 hours. The eggs were thus kept at freezing or below-freezing temperatures for 85 percent of the entire period of refrigerator exposure without being killed.

LONGEVITY OF EGGS AT ROOM TEMPERATURE

On February 17, several thousand eggs of *Ascarops strongylina* were mixed with sterile sand and put in two small glass tubes. These tubes were plugged with cotton and placed in a pint fruit jar. Water was put in the fruit jar in order to retain moisture in the jar and thus prevent drying of the sand. The jar was covered with moist paper hand towels, and a few small holes were made through the paper at the top of the jar. These jars were kept at room temperature (22° to 24° C.) until June 18, 1933, about 4 months, when the tubes were removed from the jar, and the eggs were separated from the sand and fed to dung beetles (*Aphodius granarius*). These beetles were examined 10 and 20 days later and each was found to contain several larvae of *Ascarops strongylina*. These observations show that eggs of *Ascarops strongylina* at room temperature are able to survive for a period of about 4 months.

PHYSOCEPHALUS SEXALATUS (MOLIN, 1860) DIESING, 1861

(Figs. 12–13)

Synonyms.—*Spiroptera sexalata* Molin, 1860; *S. strongylina suis labiata* Molin, 1860; *Filaria sexalata* (Molin (?), 1860) Perroncito, 1891; *S. strigis* (Linstow, 1877) Seurat, 1915; *Habronema sexalata* (Molin, 1860) Ostertag, 1932.

Hosts.—Definitive: Swine, wild boar, white-lipped peccary, tapir, cattle, horse, ass, dromedary. Intermediate: Coleoptera (*Canthon laevis, Geotrupes douei, G. stercorarius, G. stercorosus?, Gymnopleurus siurmi, G. sinnatus, Onthophagus bedeli, O. hecate, O. nebulosus, Phanaeus carnifex, P. vindex, Scarabaeus*

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sacer, *S. variolosus*). Accidental: Mammals, birds, reptiles, and amphibians for third-stage larvae; the writer (*4*) has found these larvae encysted in the stomachs of bats captured in Washington, D. C.

In addition to the above intermediate hosts, the following Coleoptera have been found by the writer to serve as intermediate hosts for *P. sexalatus: Ataenius cognatus* and *Passalus cornutus*.

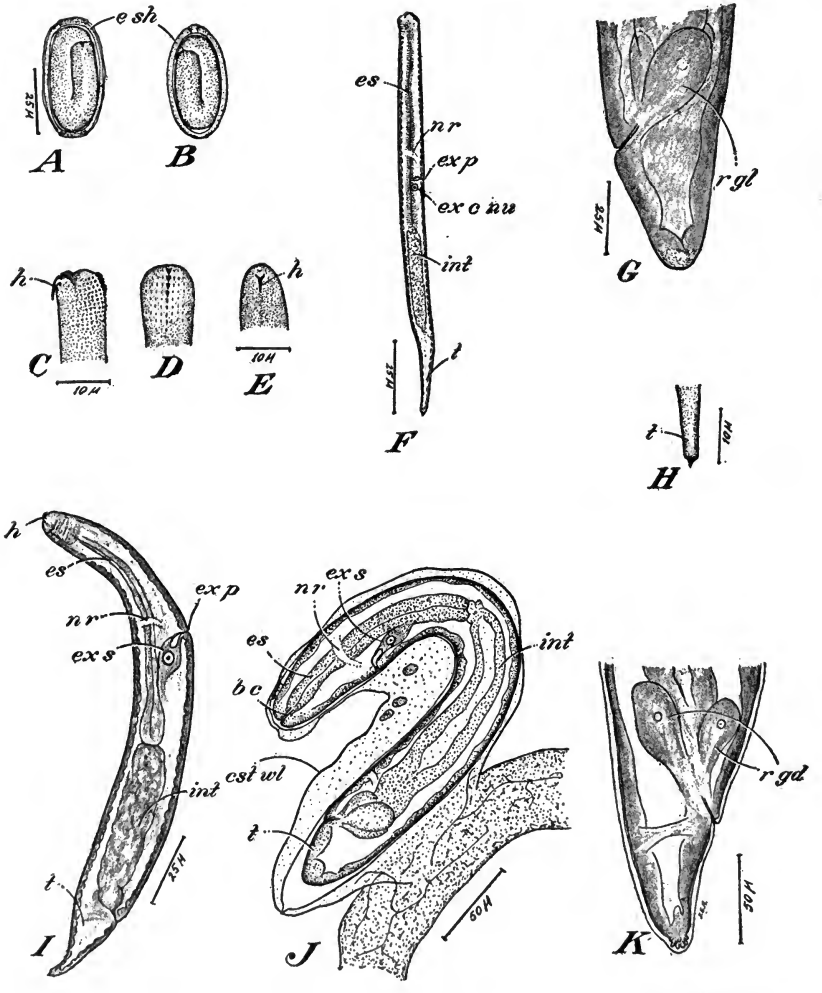

FIGURE 12.—VARIOUS STAGES IN THE DEVELOPMENT OF PHYSOCEPHALUS SEXALATUS

Egg: *A*, With fully developed shell and embryo; *B*, showing appearance of shell before it is fully formed. First-stage larva: *C*, Anterior end, lateral view; *D*, anterior end, dorsal view; *E*, anterior end, ventral view; *F*, larva from intermediate host 2 days after experimental infection, lateral view; *H*, tail; *I*, larva from intermediate host 12 days after experimental infection; *J*, larva undergoing first molt.. Second-stage larva: *G*, Tail, lateral view; *K*, posterior portion of larva undergoing second molt.

Location.—Adults in stomach of definitive host; third-stage larvae in body cavity of intermediate host, and in wall of intestine or mesentery in accidental host.

Distribution.—Africa (Algeria, Madagascar), Asia (Indo-China), Australia, Europe (Italy, Germany, Rumania), Central America (Panama), North America (United States), South America (Brazil).

Description of Egg, Embryo, and Larval Stages

EGG

Egg (fig. 12, *A*) similar to that of *Ascarops strongylina*. Ciurea (*17*) described a pluglike protuberance at one pole of the egg; Foster (*26*) was unable to confirm Ciurea's finding. The writer's observation explains the discrepancy in the findings of the above investigators, since the pluglike protuberance is conspicuous in a shell not completely developed but is not recognizable in a well-developed shell (fig. 12, *A* and *B*). In a series of measurements involving about 50 eggs, length 41μ to 45μ, width 22μ to 26μ; according to Ciurea (*17*), length 39μ, width 17μ; according to Foster (*26*), length 34μ, width 15μ. Egg contains a well-developed embryo at time of oviposition.

EMBRYO

Embryos, obtained by crushing several eggs on a slide under a cover slip, 102μ to 107μ long by 6μ in maximum width. Embryo does not undergo further development until ingested by intermediate host. Morphology of embryo resembles that of young first-stage larva.

FIRST-STAGE LARVA

Shape and size.—First-stage larva similar in shape to that of *Ascarops strongylina* (fig. 12, *F*, *H*, and *I*); before molting sometimes attains a length of 448μ and a width of 38μ (table 9); according to Seurat (*117*), 420μ in length and 40μ in width.

Cuticle.—Cuticular structure and armature as in first-stage larva of *Ascarops strongylina*, but with the following differences: Posterior of two anterior hooks (fig. 12, *C* and *E*) about 3μ long, or about twice the length of corresponding hook of *A. strongylina*; rows of spines surrounding anterior portion of body about 15 in number and extending about 14μ from anterior end; spines of each row more widely spaced than corresponding spines of *A. strongylina*; each row of spines possessing one large spine dorsally (fig. 12, *C* and *D*), a feature lacking in *A. strongylina* (fig. 10, *C*).

Alimentary tract.—In general similar to that of first-stage larva of *Ascarops strongylina*. Esophagus 76μ to 144μ long, depending on degree of development in intermediate host.

Nervous system.—As in first-stage larva of *Ascarops strongylina*. Nerve ring, 42μ to 60μ from anterior end.

Excretory system.—Excretory pore 45μ to 68μ from anterior end, leading into a short dilated duct, this duct opening into a large excretory cell possessing a large nucleus.

Genital primordium.—In living specimens, hardly distinguishable from large muscle cells of body wall.

Table 9 shows the rate of development of first-stage larvae of *Physocephalus sexalatus* in the intermediate host (*Ataenius cognatus*), the measurements having been made on different days after experimental infection.

Table 9.—*Principal measurements of 5 first-stage larvae of Physocephalus sexalatus at various periods of development in dung beetles*

Item	Period of development and measurements of larva no.—				
	1	2	3	4	5
Period of development ---- days	2	2	10	10	[1] 16
Length of body ---- microns	121	136	152	155	448
Maximum width of body ---- do	8	6	11	11	38
Length of esophagus ---- do	76	76	82	80	144
Distance of nerve ring from anterior end ---- do	42	45	50	50	60
Distance of excretory pore from anterior end ---- do	45	48	55	55	68
Length of tail ---- do	20	24	28	28	34

[1] Larva undergoing first molt.

SECOND-STAGE LARVA

Shape and size.—Larva similar in shape to second-stage larva of *Ascarops strongylina*, but tip of tail more rounded in *Physocephalus sexalatus* (fig. 12, *G*). Larvae about 456μ to 1.3 mm long by 40μ to 60μ wide, the size depending on degree of development (table 10.)

Cuticle.—Cuticle without armature at anterior end; faint transverse striations present.

Alimentary tract.—In general similar to that of corresponding larvae of *Ascarops strongylina*; esophagus 146μ to 545μ long.

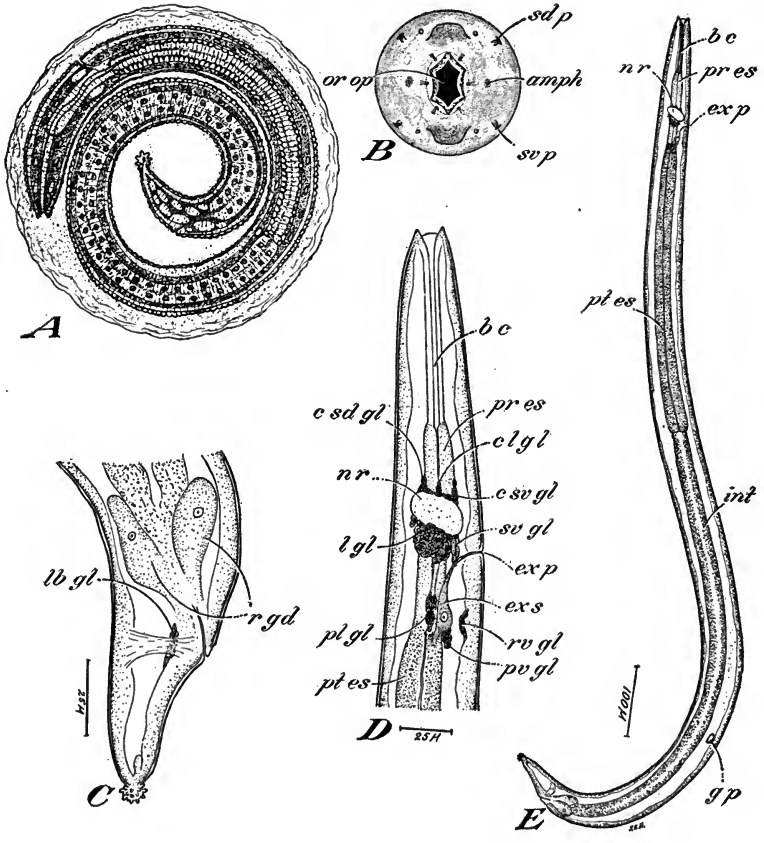

FIGURE 13.—THIRD-STAGE LARVAE OF PHYSOCEPHALUS SEXALATUS.

A, Encysted larva (from Hobmaier, 1925); *B*, anterior end of larva, en face view (from Chitwood, unpublished); *C*, posterior portion, lateral view (original); *D*, anterior portion, lateral view (original); *E*, lateral view of larva (original).

Nervous system.—Nerve ring, 60μ to 98μ from anterior end; details of this system similar in general to that of third-stage larva.

Excretory system.—As in previous stage. Excretory pore 68μ to 115μ from anterior end.

Genital primordium.—More easily recognized in older larvae of this stage, appearing as a small elliptical body; in a specimen 1.3 mm long, genital primordium 425μ from posterior end.

Table 10 shows the rate of development of second-stage larvae of *Physocephalus sexalatus* in the intermediate host (*Ataenius cognatus*), the measurement having been made on different days after experimental infection.

TABLE 10.—*Principal measurements of 4 second-stage larvae of Physocephalus sexalatus at various periods of development in dung beetles*

Item	Period of development and measurements of larva no.—			
	1	2	3	4
Period of development—days	20	20	26	[1] 34
Length of body—microns	456	462	610	1,308
Maximum width of body—do	40	40	48	60
Length of esophagus—do	146	150	210	545
Distance of nerve ring from anterior end—do	60	62	73	98
Distance of excretory pore from anterior end—do	68	71	85	115
Distance of genital primordium from posterior end—do				425
Length of tail—do	36	38	48	70

[1] Larva undergoing second molt.

THIRD-STAGE LARVA

Shape and size.—General shape and structure (fig. 13, *A-E*) of larva similar to that of corresponding stage of *Ascarops strongylina*, with the exception of the position of cervical papilla and tip of tail. Cervical papilla (deirid) on right side of body opposite to excretory pore, 131μ to 170μ from anterior end; cervical papilla (deirid) on left side near region of base of buccal cavity, 68μ to 80μ from anterior end; tip of tail ending in a characteristic small knob, about 7μ to 8μ long, bearing about 20 to 23 small digitiform cuticular processes (fig. 13, *C*). Larvae 1.35 to 1.6 mm long by 60μ to 68μ wide; according to Seurat (*117*), 940μ to 1.81 mm. long by 75μ wide; according to Hobmaier (*52*), 1.3 to 1.35 mm long by 55μ wide.

Cuticle.—With prominent transverse striations.

Alimentary tract.—In general as in *Ascarops strongylina*, with the exception of the length of the buccal cavity. Buccal cavity comparatively long, 72μ to 106μ long (fig. 13, *D* and *E*); proesophagus 80μ to 102μ long; postesophagus 436μ to 585μ long, extending posteriorly almost to equator of body; rectum 34μ to 38μ long.

Nervous system.—General structure as in corresponding stage of *Ascarops strongylina* (fig. 13, *C*, *D*, and *E*). Nerve ring 110μ to 140μ from anterior end.

Excretory system.—Excretory pore 129μ to 167μ from anterior end; according to Seurat (*117*), 145μ from anterior end. Duct of excretory pore opening into a triangular excretory sinus; sinus walls containing a large nucleus.

Genital primordium.—As in *Gongylonema pulchrum* and *Ascarops strongylina*, sex can be differentiated at this stage. Male genital primordium elliptical in shape, about 15μ long and 9μ wide, located ventrally between body wall and intestine, 320μ to 340μ from posterior end; as in *A. strongylina*, composed of 2 large epithelial cells enclosing a group of germinal cells. Female genital primordium also somewhat elliptical, about 11μ long and 7μ wide, attached to body wall ventrally by means of a cell, 428μ to 460μ from tip of tail. Measurements given in table 11 indicate that the female genital primordium is closer to the posterior end of the larva than the genital primordium of the male.

Table 11 gives the measurements of third-stage larvae of *Physocephalus sexalatus* in an intermediate host (*Ataenius cognatus*).

TABLE 11.—*Principal measurements of 6 third-stage larvae of Physocephalus sexalatus at various periods of development in dung beetles*

Item	Period of development and measurements of larva no.—					
	1[1]	2[1]	3[2]	4[2]	5[3]	6[1]
Period of development—days	36	36	50	50	50	50
Length of body—millimeters	1.35	1.40	1.42	1.45	1.59	1.60
Maximum width of body—microns	60	60	62	60	66	68
Length of buccal cavity—do	72	76	81	79	95	106
Length of proesophagus—do	80	83	94	91	98	102
Length of postesophagus—do	436	468	440	462	510	585
Distance of nerve ring from anterior end—do	110	110	117	125	130	140
Distance of excretory pore from anterior end—do	129	140	135	148	148	167
Distance of cervical papillae from anterior end:						
Right papilla—do	131	140	138	148	150	170
Left papilla—do	68	72	72	79	75	80
Distance of genital primordium from anterior end—do	428	448	320	340		460
Length of tail—do	53	53	57	50	60	68

[1] Female larva. [2] Male larva. [3] Sex undetermined.

DIFFERENCES IN FIRST THREE STAGES

The outstanding differential features of the first three developmental stages of *Physocephalus sexalatus* are similar to those already noted for *Ascarops strongylina*, except that in the former the knob at the tip of the tail in the third-stage larva possesses several digitiform processes, whereas in the latter the knob is smooth.

Development in the Intermediate Host

Eggs of *Physocephalus sexalatus* were obtained and fed to dung beetles (*Ataenius cognatus*) as described for *Ascarops strongylina*. Beetles dissected 24 hours after experimental infection showed several newly hatched first-stage larvae in the body cavity. About 16 days after infection, first-stage larvae, about 448μ long, were found encysted in the Malpighian tubules of the beetles and were undergoing the first molt (fig. 12, *J*). The cyst wall at this time is very thin, and in addition to the larva, it encloses 2 or 3 small cells, probably fat cells. Second-stage larvae were noted 20 to 26 days after experimental infection; larvae undergoing the second molt were noted in beetles 34 days after infection; third-stage larvae were noted in beetles 36 days after infection. During the development of the larva, the cyst increased in size, being about 300μ to 650μ in greater diameter and 420μ to 700μ in lesser diameter at the time the cyst was fully developed (fig. 13, *A*). Completely formed cysts were found either attached to Malpighian tubules or free in the abdominal portion of the body cavity, frequently interlaced superficially by small tracheal tubules of the insect.

Hobmaier (*52*) in his study of the larval stages of *Physocephalus sexalatus*, shows in his figures that the larva molts four times in the intermediate host; Seurat (*115*, *116*, *117*) and the writer find that the larva undergoes only two molts in the intermediate host. The latter observations are in harmony with the known facts of nematode development.

Observations on Effects of Environment

RESISTANCE OF EGGS TO LOW TEMPERATURES

On February 17, 1933, about 1,000 eggs of *Physocephalus sexalatus* were mixed with sterile sand, and the mixture was placed in two small glass tubes. These tubes were plugged with cotton and placed in a refrigerator. On March 9, 20 days later, the tubes were removed from the refrigerator. The eggs were separated from the sand, placed on pieces of blotting paper, and the blotting paper and eggs put in a tube containing several dung beetles (*Ataenius cognatus*). These beetles were examined at various intervals from 10 to 20 days after exposure to infection, and each was found to contain several young larvae of *Physocephalus sexalatus*.

The temperature range during the 20 days' exposure in the refrigerator was as follows: Minimum, −4° C; maximum, 2°. The total time during which the temperature was 2° was 48 hours; 1°, 24 hours; 0°, 48 hours; −1°, 24 hours; −2°, 216 hours; −3°, 24 hours; −4°, 76 hours. The eggs were thus kept at freezing or below-freezing temperatures for about 85 percent of the entire period of refrigerator exposure without being killed.

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METASTRONGYLIDAE

METASTRONGYLUS SALMI GEDOELST, 1923

(Figs. 14–15)

Synonym.—*Metastrongylus elongatus* Salm, 1918, not Railliet and Henry, 1911.

Hosts.—Definitive: Swine. Intermediate: *Lumbricus terrestris* and *Helodrilus caliginosus* var. *trapezoides*.

Location.—Adults in trachea, bronchi, and bronchioles of definitive host; third-stage larvae in circulatory system and in walls of alimentary tract (usually esophagus) of intermediate host.

Distribution.—Africa (Belgian Congo), Asia (Java, Philippine Islands), Europe (Spain), and North America (United States).

Description of Egg, Embryo, and Larval Stages

EGG

Eggshell thick and elliptical in shape, possessing rough surface with the appearance of small mammillations (fig. 14, *A*); incompletely developed eggshell showing a thin covering, and within it an inner vitelline membrane enclosing embryo (fig. 14, *B*). Before the egg is deposited by the female worm the shell appears to undergo considerable hardening and contraction, this process possibly giving rise to the unevenness found on the surface of the fully developed eggshell. In a series of measurements involving about 50 fully developed eggs, length 43μ to 57μ, width 38μ to 41μ; according to Gedoelst (*32*), length 52.5μ to 55.5μ, width 33μ to 40μ. Egg contains a well-developed embryo at time of oviposition.

The eggs of *Metastrongylus salmi*, as well as those of *M. elongatus* and *Choerostrongylus pudendotectus* discussed in this bulletin, contrary to reports of some other investigators, usually pass out of the host unhatched. Hatching usually does not take place until the eggs are taken into the body of a susceptible intermediate host.

EMBRYO

Embryos, obtained by pressing several embryonated eggs under cover slip, 275μ to 295μ long by 12μ in maximum width; possess numerous and somewhat large granules; usually tightly coiled within eggshells as shown in figure 14, *A*. When embryo is mechanically removed from eggshell, posterior half of body is coiled ventrad, giving embryo appearance of open figure 6 (fig. 14, *D*). Embryo as found in egg in freshly passed feces of swine usually does not leave eggshell nor undergo additional development before being ingested by intermediate host.

FIRST- AND SECOND-STAGE LARVAE

First three larval stages of this parasite not distinctly separated from one another as are those of most strongyle larvae. Soon after cuticle of first molt becomes separated from anterior end of body, a second molt is evident (fig. 14, *E, G*). First cuticle usually shed before cuticle of second molt becomes completely detached from body of larva; second cuticle is, however, retained throughout life of larva in intermediate host; period of second stage is then possibly represented by short period from time that first and second molts are evident, that is, second stage is represented by a molt, but is otherwise more or less suppressed so far as a distinct existence for a definite period is concerned. Differentiation of various larval molts in *Metastrongylus salmi* involves essentially the same features as those pointed out by Schwartz and Alicata (*111*) for larvae of *M. elongatus* and *Choerostrongylus pudendotectus*.

Shape and size.—Larvae of the first and second stages slender, with tapering anterior and posterior portions. Anterior end (fig. 14, *C*) of young first-stage larva rounded and slightly set off by a small constriction, which is not evident in older larva of first stage. In first-stage larva, posterior end (fig. 14, *D*) has a broad rounded tip turned ventrad; after the first molt, tip of tail more pointed (fig. 14, *F*). First-stage larvae 1 day after infection, 275μ to 300μ long by 12μ wide; at time of first molt, larvae 500μ to 525μ long by 22μ to 26μ wide; undergoing second molt, 550μ to 610μ long by 26μ to 28μ wide (table 12).

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Cuticle.—Very thin, transparent, with fine transverse striations; cuticle, in contrast with that of other heteroxenous nematodes discussed in this bulletin, with no armature.

Alimentary tract.—Oral opening leading into a short tripartite buccal cavity lined with three longitudinally arranged annules; these annules best distinguished in third-stage larva (fig. 15, *D*). Esophagus 110μ to 160μ long, slender, with a

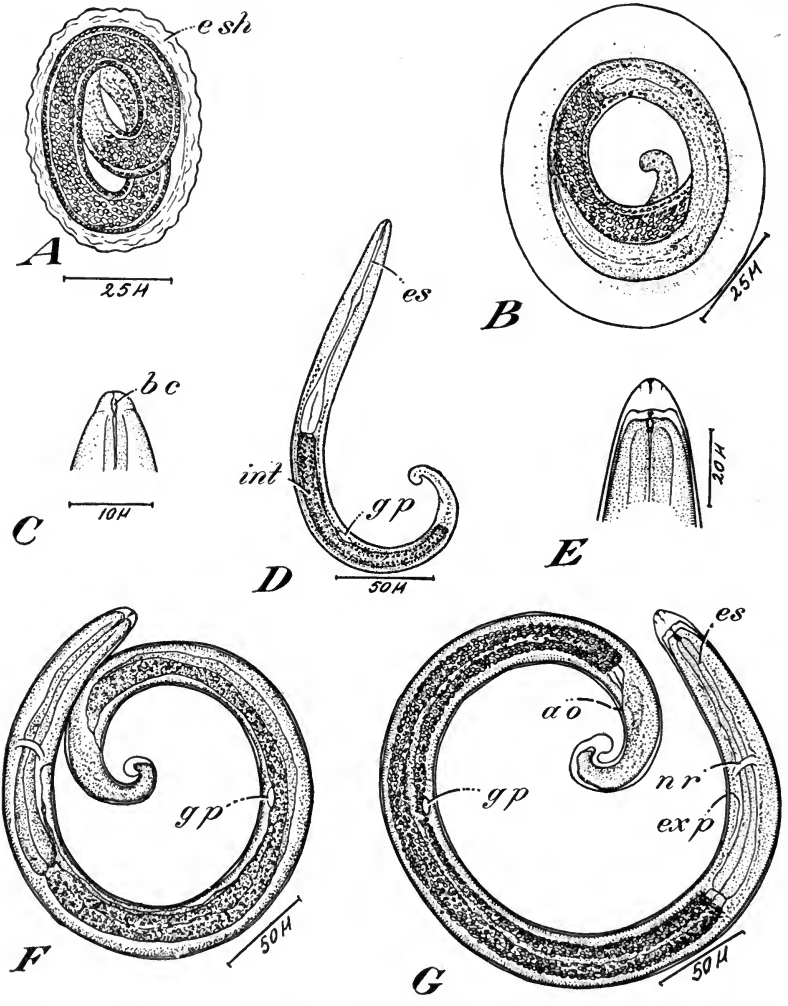

FIGURE 14.—VARIOUS STAGES IN THE DEVELOPMENT OF METASTRONGYLUS SALMI.

Egg: *A*, With fully developed embryo; *B*, showing incompletely formed shell.
First-stage larva: *C*, Anterior portion; *D*, newly hatched larva; *F*, larva undergoing first molt.
Second-stage larva: *E* and *G*, On verge of second molt while still enclosed within the cuticle of first molt.

distinct swelling at its anterior third (fig. 14, *D*). Intestine slender, its walls closely packed with large dark-brown granules; intestine connecting with a short and narrow rectum.

Nervous system.—Larva stained with aqueous methylene blue, showing nerve ring 50μ to 72μ from anterior end; nerve ring surrounded by several nuclei of nerve cells.

Excretory system.—Excretory pore 58μ to 80μ from anterior end; its duct connecting posteriorly with excretory glands.

Genital primordium.—Represented by small ellipsoidal group of cells, ventral in position, 160μ to 330μ from anterior end.

TABLE 12.—*Principal measurements of 10 first- and second-stage larvae of Metastrongylus salmi at various periods of development in earthworms*

Item	Period of development and measurements of larva no.—									
	1	2	3	4	5	6	7	8	9	10
Period of development.....days..	1	1	8	[1] 13	[1] 13	[1] 13	[2] 15	[2] 15	[2] 15	[2] 15
Length of body.....microns..	275	300	380	500	520	525	550	585	600	610
Maximum width of body.....do....	12	12	18	22	26	26	26	26	28	28
Length of esophagus.....do....	110	112	115	120	130	130	145	150	155	160
Distance of nerve ring from anterior end.....microns..	50	50	55	60	70	70	68	72	72	72
Distance of excretory pore from anterior end.....microns..	58	60	65	72	72	78	78	80	80	80
Distance of genital primordium from anterior end.....microns..	160	164	200	280	285	285	290	318	325	330
Length of tail.....do....	28	28	34	38	40	45	48	48	48	50

[1] Larva undergoing first molt.
[2] Larva undergoing second molt.

Table 12 shows the rate of development of *Metastrongylus salmi* in the intermediate host (*Helodrilus caliginosus* var. *trapezoides*), the measurements having been made on different days after experimental infection.

THIRD-STAGE LARVA

Shape and size.—Shape of larva, mostly as in previous stages (fig. 15, *E*). Each lateral half of head, in en face view, apparently surrounded by 3 small elevations (fig. 15, *C*), probably representing the beginning of the formation of the 2 lateral trilobed lips of the adult worm. Head with an outer circle of 2 subdorsal and 2 subventral papillae and 2 lateral amphids; an inner circle of 2 subdorsal and 2 subventral small papillae also apparently present. Tail tapering, terminating in a pointed tip; just above tip, lateral view, 2 dorsal notches somewhat indistinct (fig. 15, *B* and *F*). Larvae 550μ to 630μ long, enclosed in sheath of last molt.

Cuticle.—With prominent transverse striations.

Alimentary tract.—Oral opening leading into a tripartite buccal cavity about 5μ long, lined with three longitudinally arranged annules (fig. 15, *D*). Esophagus strongyliform, 150μ to 175μ long. Intestine slender, lying, for the most part, close to ventral side of body wall, and opening into a narrow rectum about 22μ long.

Nervous system.—Nerve ring 64μ to 72μ from anterior end of body. In stained specimens, 6 nerve strands anterior to nerve ring, forming papillary nerves, 2 subdorsal, 2 subventral, and 2 lateral. Posterior to nerve ring, 2 large lateral ganglia, each connected posteriorly to the posterolateral ganglion, the latter extending midway between nerve ring and end of esophagus. Dorsally and ventrally, groups of nuclei of nerve cells, possibly representing dorsal and ventral ganglia. Excretory duct surrounded by a group of nuclei of nerve cells; slightly posterior to it, retrovesicular ganglion represented by a group of nuclei of nerve cells.

Excretory system.—Excretory pore 72μ to 80μ from anterior end, leading into long excretory glands extending posterior to rectum (fig. 15, *E*).

Genital primordium.—In about same position as in previous stages, 300μ to 345μ from anterior end.

Table 13 shows the measurements of third-stage larvae of *Metastrongylus salmi* in an intermediate host (*Helodrilus caliginosus* var. *trapezoides*).

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TABLE 13.—*Principal measurements of 5 third-stage larvae of Metastrongylus salmi at various periods of development in earthworms*

Item	Period of development and measurements of larva no.—				
	1	2	3	4	5
Period of development ---- days	18	18	30	30	30
Length of body ---- microns	550	550	550	575	630
Maximum width of body ---- do	26	26	26	26	26
Length of esophagus ---- do	170	170	150	160	175
Distance of nerve ring from anterior end ---- do	64	64	64	68	72
Distance of excretory pore from anterior end ---- do	72	78	76	78	80
Distance of genital primordium from anterior end ---- do	315	305	300	325	345
Length of tail ---- do	50	40	40	40	45

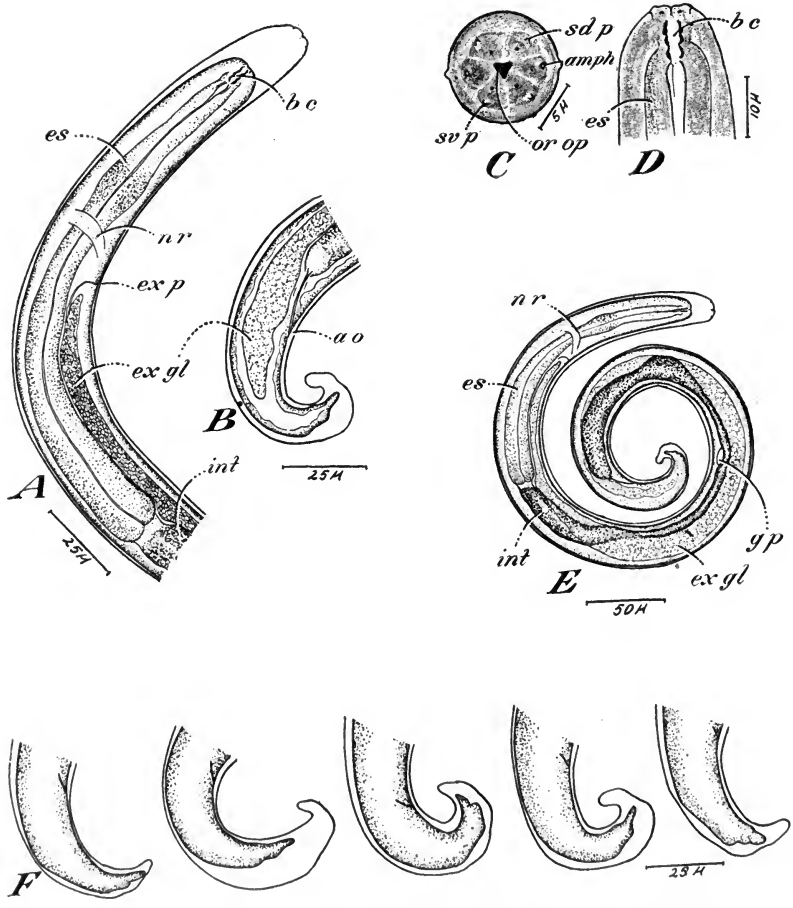

FIGURE 15.—THIRD-STAGE LARVAE OF METASTRONGYLUS SALMI.

A, Anterior portion, lateral view; *B*, posterior portion, lateral view; *C*, anterior end, en face view; *D*, anterior end, lateral view; *E*, lateral view of larva; *F*, variations noted in tails.

DIFFERENCES IN FIRST THREE STAGES

The outstanding differential features of the first three developmental stages of *Metastrongylus salmi* are as follows:

First-stage larva.—About 275μ to 380μ long by 12μ to 18μ wide; anterior end conical and somewhat set off by a small constriction; cuticle at anterior end conical when loosened in preparation for first molt.

Second-stage larva.—About 500μ to 525μ long by 22μ to 26μ wide; anterior end slightly flattened.

Third-stage larva.—About 550μ to 630μ long, enclosed in a sheath formed by cuticle of second stage; sheath flattened at anterior end (fig. 14, *E*); tail with 2 somewhat indistinct dorsal notches when viewed laterally.

Development in Intermediate Host

Eggs of *Metastrongylus salmi* were obtained by chopping up gravid female worms in a few drops of distilled water. This material was then transferred to a 250-cc beaker and mixed with a small quantity of soil; several live earthworms (*Helodrilus caliginosus* var. *trapezoides*) were put in this soil. In order that the earthworms used should be free from natural infestation with this parasite, they were collected from the yard of a city dwelling. Earthworms were allowed to remain overnight in the soil containing the lungworm eggs and were then transferred to a beaker containing soil free from lungworm eggs. These experiments were carried out at room temperatures (22° to 24° C.).

Earthworms dissected about 30 hours after being exposed to infection in soil contained several first-stage larvae in the wall of the esophagus, especially the posterior part of this organ. In earthworms dissected about 13 days after infection, several larvae were undergoing the first molt (fig. 14, *F*); earthworms dissected 2 days later contained larvae in the process of the second molt, while still enclosed in the cuticle of the first molt (fig. 14, *E* and G), the larvae having 2 sheaths at this time. Completely developed third-stage larvae were recovered from the esophageal wall and hearts of earthworms 18 days after infection.

Observations on Effects of Environment

longevity of third-stage larvae in body of intermediate host

On March 24, 1933, 4 earthworms which were experimentally infected with *Metastrongylus salmi* were placed in a large, tightly nailed, wooden box containing soil. This box was placed outdoors, partially underground, and was covered to prevent rain from falling upon it. On July 24, 4 months later, only 1 earthworm was found in the box; apparently the others had died. This earthworm was found to harbor 4 third-stage larvae of *Metastrongylus salmi*, 1 larva in the esophageal wall, and 3 larvae in one of the hearts. These larvae, after being isolated from the earthworm and placed in water, showed considerable activity. The above experiment shows that larvae of *Metastrongylus salmi* may remain in the body of the intermediate host for at least 4 months.

METASTRONGYLUS ELONGATUS (DUJARDIN, 1845) RAILLIET AND HENRY, 1911

(Figs. 16-17)

Synonyms.—*Gordius pulmonalis apri* Ebel, 1777; *Ascaris apri* Gmelin, 1789; *A. filiformis* Schrank, 1788; *Fusaria apri* Zeder, 1803; *Strongylus suis* Rudolphi, 1809; *S. paradoxus* Mehlis, 1831; *S. elongatus* Dujardin, 1845; *S. longivaginatus* Diesing, 1851; *Metastrongylus paradoxus* (Mehlis, 1831) Molin, 1860; *Filaria trachealis* Cobbold, 1864; *S. apri* (Gmelin, 1789) R. Blanchard, 1895; *Cloacina octodactyla* Linstow, 1906; *M. apri* (Gmelin, 1789) Railliet and Henry, 1907.

Hosts.—Definitive: Swine, cattle, sheep, goat, deer, roe deer, man, and, by experimental feeding, dog, as reported by the writer (*6*). Intermediate: *Helodrilus foetidus, H. caliginosus* var. *trapezoides, Lumbricus terrestris, L. rubellus, Bimastus tenuis.*

Location.—Adults in trachea, bronchi, and bronchioles of definitive host; third-stage larvae in circulatory system or wall of intestine or, usually, esophagus of intermediate host.

Distribution.—Africa (Belgian Congo), Asia (Annam, China, Japan), Australia, Europe, North America (British West Indies, Puerto Rico, Mexico, United States), South America (Argentina).

Description of Egg, Embryo, and Larval Stages

EGG

As in *Metastrongylus salmi*, egg, fully developed, with thick shell, elliptical in shape, and with a corrugated surface (fig. 16, *A*). In a series of measurements involving about 50 eggs, length 45μ to 57μ, width 38μ to 41μ; according to Gedoelst (*32*), length 51μ to 54μ, width 33μ to 36μ; according to Zebrowski (*140*), length 50μ to 80μ. Egg contains a well-developed embryo at time of oviposition.

EMBRYO

Embryos similar to those of *Metastrongylus salmi* (fig. 16, *B*), 275μ to 305μ long by 12μ wide.

FIRST- AND SECOND-STAGE LARVAE

Shape and size.—Shape of these larvae same as in corresponding stages of *Metastrongylus salmi.* Newly hatched larvae 275μ to 305μ long by 12μ wide; at time of first molt, 520μ to 540μ long by 22μ wide; undergoing second molt, 560μ to 650μ long by 26μ to 28μ wide (table 14).

Cuticle.—Thin, with fine transverse striations.

Alimentary tract.—Morphologically, as in *Metastrongylus salmi;* esophagus 114μ to 160μ long.

Nervous system.—As in *Metastrongylus salmi;* nerve ring 52μ to 76μ from anterior end.

Excretory system.—Excretory pore 58μ to 86μ from anterior end, its duct connecting posteriorly with excretory glands.

Genital primordium.—Small, ellipsoidal, and ventral in position, 160μ to 365μ from anterior end.

Table 14 shows the rate of development of first- and second-stage larvae of *Metastrongylus elongatus* in an intermediate host (*Helodrilus caliginosus* var. *trapezoides*), the measurements having been made at different days after experimental infection.

TABLE 14.—*Principal measurements of 9 first- and second-stage larvae of Metastrongylus elongatus at various periods of development in earthworms*

Item	Period of development and measurements of larva no.—								
	1	2	3	4	5	6	7	8	9
Period of development.....days	1	1	9	[1] 15	[1] 15	[2] 19	[2] 19	[2] 19	[2] 19
Length of body.....microns	275	305	392	520	540	560	600	645	650
Maximum width of body.....do	12	12	18	22	22	26	28	28	28
Length of esophagus.....do	114	117	120	130	138	145	148	150	160
Distance of nerve ring from anterior end.....microns	52	52	56	68	68	68	72	76	76
Distance of excretory pore from anterior end.....microns	58	64	68	72	78	80	82	86	86
Distance of genital primordium from anterior end.....microns	160	164	210	285	280	298	328	368	365
Length of tail.....do	28	28	34	38	38	38	40	48	50

[1] Larva undergoing first molt.
[2] Larva undergoing second molt.

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THIRD-STAGE LARVA

Shape and size.—Shape of larva resembles that of corresponding stage of *Metastrongylus salmi* (fig. 16, *D–G*); in lateral view of posterior portion, notches

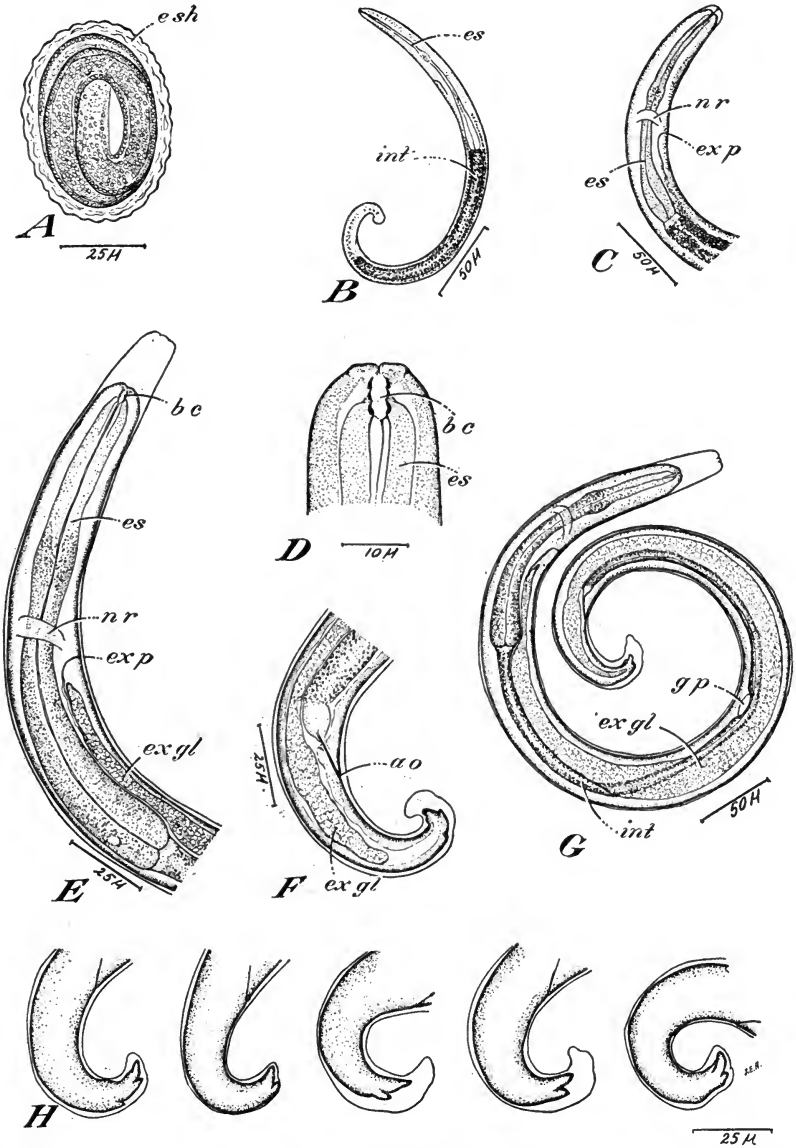

FIGURE 16.—VARIOUS STAGES IN THE DEVELOPMENT OF METASTRONGYLUS ELONGATUS.

A, Egg with fully developed embryo.
First-stage larva: *B*, Newly hatched; *C*, anterior portion of larva undergoing first molt.
Third-stage larva: *D*, Anterior end, lateral view: *E*, anterior portion, lateral view; *F*, posterior portion, lateral view; *G*, lateral view of larva; *H*, variations noted in tails.

near tip of tail usually more prominent in *M. elongatus* (fig. 16, *H*) than in *M. salmi*. Larvae 625μ to 665μ long by 26μ wide, enclosed in sheath of last molt.

Cuticle.—With prominent transverse striations.

Alimentary tract.—Morphologically, as in *Metastrongylus salmi;* esophagus 155μ to 177μ long.

Nervous system.—In general, as in *Metastrongylus salmi;* nerve ring 72μ to 80μ from anterior end.

Excretory system.—Excretory pore 80μ to 87μ from anterior end, leading into long excretory glands extending posterior to rectum (fig. 16, *G*).

Genital primordium.—Position resembles that of previous stages; 340μ to 390μ from anterior end.

Table 15 gives the measurements of third-stage larvae of *Metastrongylus elongatus* in an intermediate host (*Helodrilus caliginosus* var. *trapezoides*).

TABLE 15.—*Principal measurements of 5 third-stage larvae of Metastrongylus elongatus at various periods of development in earthworms*

Item	Period of development and measurements of larva no.—				
	1	2	3	4	5
Period of development ..... days	20	20	28	28	28
Length of body ..... microns	625	630	650	650	665
Maximum width of body ..... do	26	26	26	26	26
Length of esophagus ..... do	155	160	160	160	177
Distance of nerve ring from anterior end ..... do	72	72	75	75	80
Distance of excretory pore from anterior end ..... do	80	87	87	87	84
Distance of genital primordium from anterior end ..... do	340	360	390	390	390
Length of tail ..... do	60	60	62	60	60

DIFFERENCES IN FIRST THREE STAGES

The outstanding differential features of the three developmental stages of *Metastrongylus elongatus* are as given for *M. salmi.*

DEVELOPMENT IN INTERMEDIATE HOST

Earthworms (*Helodrilus caliginosus* var. *trapezoides*) were exposed to soil containing eggs of *Metastrongylus elongatus,* in the same manner as described for *M. salmi.* Earthworms dissected about 16 hours after being exposed to infected soil contained several first-stage larvae in the wall of the esophagus. In earthworms dissected 15 days after infection, several larvae were undergoing the first molt (fig. 16, *C*). Earthworms dissected 4 days later contained larvae in the process of shedding the second cuticle, while still enclosed in the cuticle of the first molt. Completely developed third-stage larvae were recovered from the esophagus and hearts of earthworms 20 days after infection (fig. 17, *A* and *B*).

Occasionally, larvae which had not yet undergone the first molt were found in the circulatory system, especially in the hearts of the earthworm. In this connection Schwartz and Alicata (*109*) pointed out that the migration of the larvae of *Metastrongylus elongatus* and *Choerostrongylus pudendotectus* in the blood vessels of the intermediate host was not an essential feature in the development of the larvae, since complete larval development may take place in the walls of the digestive tract.

The time of occurrence of the various molts seems variable; Hobmaier and Hobmaier (*49*) in referring to the development of *Metastongylus elongatus* in earthworms, state that a molt took place 10 days after infection. Schwartz and Alicata (*109*) reported that evidence of first and second molts was found on the eighth and ninth days, respectively, after infection.

OBSERVATIONS ON EFFECTS OF ENVIRONMENT

On December 20, 1932, 15 earthworms (*Helodrilus caliginosus* var. *trapezoides*) which had been experimentally infected with *Metastrongylus elongatus* were placed in a box outdoors, as described for *M. salmi*. On September 20, 1933, 9 months later, only 2 earthworms were recovered from the box; apparently the others had died. One of these earthworms harbored 2 larvae in the esophageal wall and 3 larvae coiled in one of the hearts; the other earthworm harbored 2

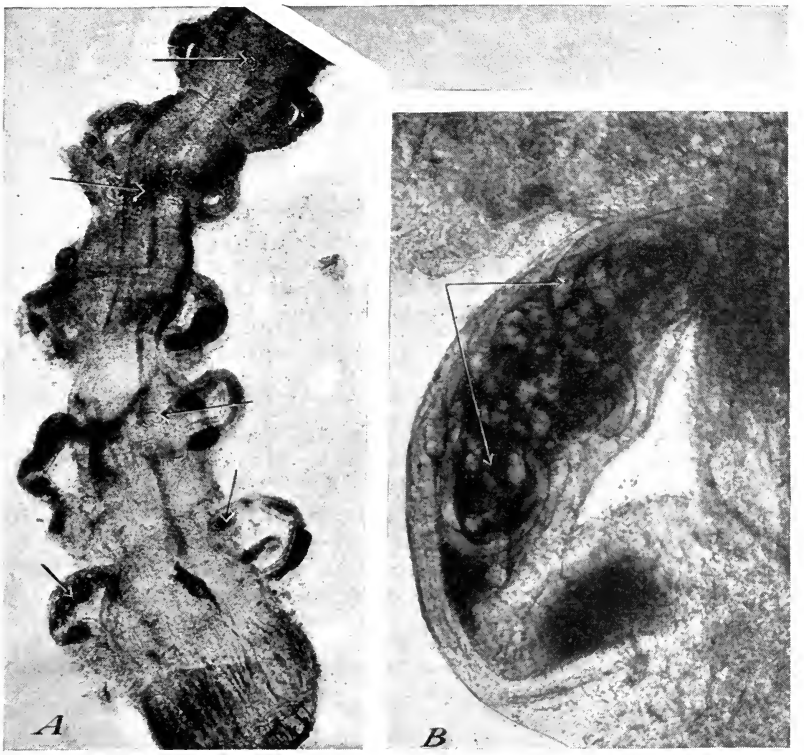

FIGURE 17.—*A*, Esophagus of earthworm containing larvae of *Metastrongylus elongatus* (indicated by arrows) in hearts and esophageal wall 30 days after experimental infection; *B*, heart of earthworm enclosing larvae of *M. elongatus* (indicated by arrows).

larvae in the hearts. These larvae showed considerable activity when isolated and placed in water. These observations show that third-stage larvae of *M. elongatus* were able to survive in the tissues of the intermediate host for at least 9 months, including the winter and summer seasons.

CHOEROSTRONGYLUS PUDENDOTECTUS (WOSTOKOW, 1905) SKRJABIN, 1924

(Fig. 18)

Synonyms.—*Metastrongylus pudendotectus* Wostokow, 1905; *M. brevivaginatus*, Railliet and Henry, 1907; *Choerostrongylus brevivaginatus* (Railliet and Henry, 1907) Gedoelst, 1923.

Hosts.—Definitive: Swine. Intermediate: *Helodrilus foetidus*, *H. caliginosus* var. *trapezoides*, *Lumbricus terrestris*, *L. rubellus*.

Location.—Adults in trachea, bronchi, and bronchioles of definitive host; third-stage larvae in circulatory system and in walls of alimentary tract (usually esophagus) of intermediate host.

Distribution.—Africa (Belgian Congo), Asia (Annam), Europe, North America (British West Indies, United States), and South America (Argentina).

Description of Egg, Embryo, and Larval Stages

EGG

As in *Metastrongylus salmi*, egg fully developed with thick shell, elliptical in shape, and with a corrugated surface (fig. 18, *B*). In a series of measurements involving about 50 eggs, length 60μ to 64μ, width 43μ to 45μ; according to Gedoelst (*32*), length 57μ to 63μ, width 39μ to 42μ; according to Zebrowski (*140*), length 70μ to 100μ, width 50μ to 80μ. Zebrowski's measurements indicate that he was measuring eggs with incompletely developed shells. Egg contains a well-developed embryo at time of oviposition.

EMBRYO

Embryos similar to those of *Metastrongylus salmi* (fig. 18, *D*), 300μ to 315μ long by 12μ to 14μ wide.

FIRST- AND SECOND-STAGE LARVAE

Shape and size.—Shape of these larvae similar to that of corresponding stage of *Metastrongylus salmi* (fig. 18, *D*). Larvae newly hatched, 300μ to 315μ long by 12μ to 14μ wide; at time of first molt, 525μ to 548μ long by 22μ wide; undergoing second molt, 580μ to 630μ long by 26μ to 28μ wide (table 16).

Cuticle.—With fine transverse striations.

Alimentary tract.—Morphologically, as in *Metastrongylus salmi;* esophagus, 117μ to 160μ long.

Nervous system.—Nervous system as in *Metastrongylus salmi;* nerve ring, 52μ to 76μ from anterior end.

Excretory system.—Excretory pore 64μ to 86μ from anterior end, its duct connecting posteriorly with excretory glands.

Genital primordium.—Small and ellipsoidal, 164μ to 355μ from anterior end.

Table 16 shows the rate of development of first- and second-stage larvae of *Choerostrongylus pudendotectus* in an intermediate host (*Helodrilus caliginosus* var. *trapezoides*), the measurements having been made on different days after experimental infection.

TABLE 16.—*Principal measurements of 8 first- and second-stage larvae of Choerostrongylus pudendotectus at various periods of development in earthworms*

Item	Period of development and measurements of larva no.—							
	1	2	3	4	5	6	7	8
Period of development.....days	1	1	9	[1] 14	[1] 15	[2] 18	[2] 18	[2] 18
Length of body.....microns	300	315	385	525	548	580	590	630
Maximum width of body.....do	12	14	18	22	22	26	28	28
Length of esophagus.....do	117	120	122	125	130	140	140	160
Distance of nerve ring from anterior end.....do	52	54	56	66	70	70	72	76
Distance of excretory pore from anterior end.....do	64	70	72	72	76	80	82	86
Distance of genital primordium from anterior end.....microns	164	170	215	290	296	315	330	355
Length of tail.....do	28	30	34	38	40	40	45	50

[1] Larva undergoing first molt.
[2] Larva undergoing second molt.

THIRD-STAGE LARVA

Shape and size.—Larvae resembling in shape those of corresponding stages of *Metastrongylus salmi* (fig. 18, *C* and *E*). In lateral view, notches on tip of tail usually as in *M. salmi*, but not so prominent as those of *M. elongatus* (fig. 18, *G*), the findings of the writer being contrary to those of Hobmaier and Hobmaier (*51*), who state that the notches at the tip of the tail of *Choerostrongylus pudendotectus*

are deeper than those of *Metastrongylus elongatus*. Larvae 600μ to 655μ long by 26μ wide, enclosed in sheath of last molt.

Cuticle.—With prominent transverse striations.

Alimentary tract.—Morphologically similar to that of corresponding stage of *Metastrongylus salmi;* esophagus, 160μ to 180μ long.

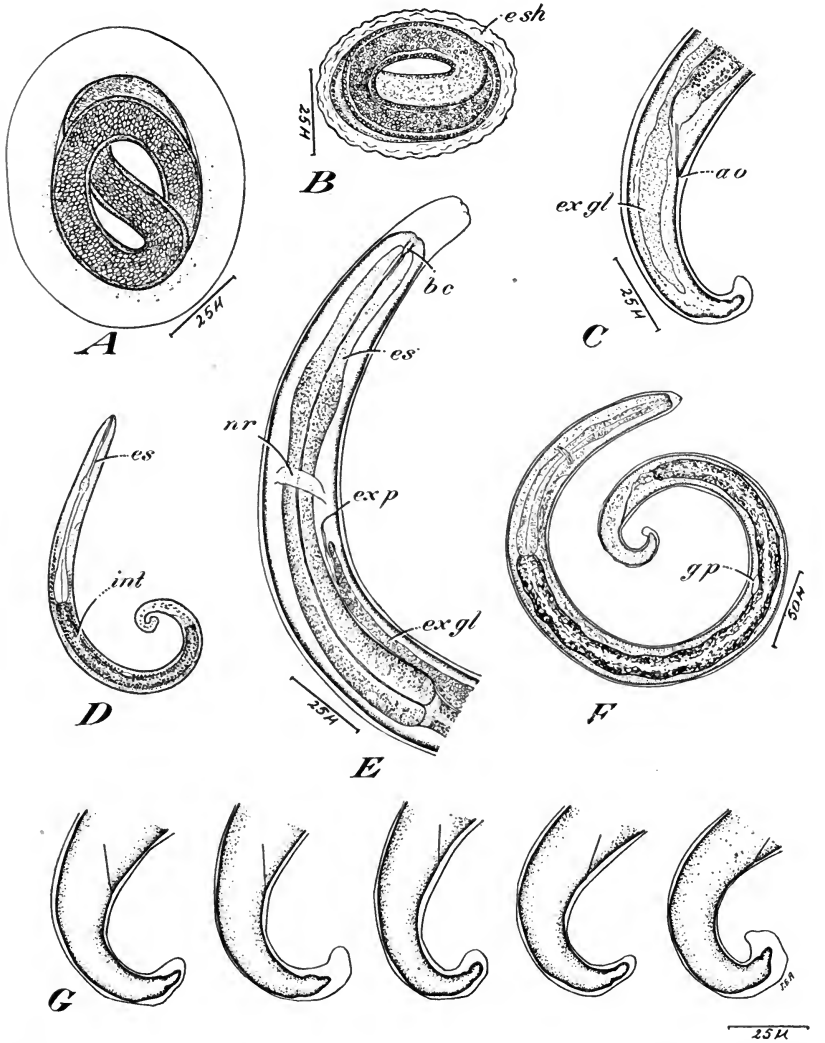

FIGURE 18.—VARIOUS STAGES IN THE DEVELOPMENT OF CHOEROSTRONGYLUS PUDENDOTECTUS.

Egg: *A*, Showing incompletely formed shell; *B*, with fully developed shell and embryo.
First-stage larva: *D*, Newly hatched; *F*, undergoing first molt.
Third-stage larva: *C*, Posterior portion, lateral view; *E*, anterior portion, lateral view; *G*, variations noted in tails.

Nervous system.—In general, as in *Metastrongylus salmi;* nerve ring 72μ to 82μ from anterior end.

Excretory system.—Excretory pore 84μ to 87μ from anterior end, leading into long excretory glands extending posterior to rectum (fig. 18, *C* and *E*).

Genital primordium.—In approximately the same position as in previous stage; 342μ to 390μ from anterior end.

Table 17 shows the measurements of third-stage larvae of *Choerostrongylus pudendotectus* in an intermediate host (*Helodrilus caliginosus* var. *trapezoides*).

TABLE 17.—*Principal measurements of 5 third-stage larvae of Choerostrongylus pudendotectus at various periods of development in earthworms*

Item	Period of development and measurements of larva no.—				
	1	2	3	4	5
Period of development.....days	19	19	19	25	25
Length of body.....microns	600	625	640	650	655
Maximum width of body.....do	26	26	26	26	26
Length of esophagus.....do	160	160	170	175	180
Distance of nerve ring from anterior end.....do	72	75	75	80	82
Distance of excretory pore from anterior end.....do	84	84	87	87	87
Distance of genital primordium from anterior end.....do	342	360	380	390	390
Length of tail.....do	55	60	55	60	62

The outstanding differential features of the three developmental stages of *Choerostrongylus pudendotectus* are as given for *Metastrongylus salmi*.

DEVELOPMENT IN INTERMEDIATE HOST

Earthworms (*Helodrilus caliginosus* var. *trapezoides*) were exposed to soil containing eggs of *Choerostrongylus pudendotectus*, in the same manner as described for *Metastrongylus salmi*. Earthworms dissected about 30 hours after exposure to infected soil contained several first-stage larvae in the wall of the esophagus. In earthworms dissected 14 days after infection, several larvae were undergoing the first molt (fig. 18, *F*). Earthworms dissected 4 days later contained larvae in the process of shedding the second cuticle, while still enclosed in the cuticle of the first molt. Earthworms dissected 19 days after infection contained fully developed third-stage larvae. As in *M. elongatus*, larvae which had not yet undergone the first molt were found in the circulatory system, especially in the hearts of the earthworms.

OBSERVATIONS ON EFFECTS OF ENVIRONMENT

On December 20, 1932, 15 earthworms (*Helodrilus caliginosus* var. *trapezoides*) which had been experimentally infected with *Choerostrongylus pudendotectus* were placed in a box outdoors, as described for *Metastrongylus salmi*. Nine months later, only 1 earthworm was recovered from the box; apparently the others had died. In this earthworm there were found 4 third-stage larvae, 2 larvae in the esophageal wall and 2 larvae in one of the hearts. These larvae showed considerable activity when isolated and placed in water. These observations show that third-stage larvae of *Choerostrongylus pudendotectus* were able to survive in the tissues of the intermediate host for at least 9 months, including the winter and summer seasons.

ASCARIDAE

ASCARIS SUUM GOEZE, 1782

(Fig. 19)

Synonyms.—*Ascaris lumbricoides* Linnaeus, 1758, of authors; *A. suilla* Dujardin, 1845.

Hosts.—Definitive: Swine, sheep, cattle, orang-utan, squirrel. Since *Ascaris suum* is morphologically identical with *A. lumbricoides*, so far as the literature indicates, the reports of *Ascaris* for the above-mentioned hosts other than swine, the

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type host of *A. suum*, are possibly reports of *A. suum* and possibly of *A. lumbricoides*. Larval forms of *A. suum* in goat, guinea pig, mouse, rabbit, rat, and probably many other mammals.

Location.—Adults in small intestine usually, but sometimes as wandering parasites in esophagus, stomach, cecum, respiratory passages, liver, gall bladder, pancreas, kidneys, and possibly other parts of the body.

Distribution.—Cosmopolitan.

Description of Egg and Embryo

EGG

Egg usually rounded or elliptical; shell thick, covered with an albuminous coat irregularly mammillated (fig. 19, *A*), and usually stained yellowish brown by intestinal contents. It has been pointed out by many authors, namely, Miura and Nishiuchi (*75*), Foster (*27*), Wharton (*136*), Martin (*73*), Otto (*83*), and Keller (*53*), that unfertilized *Ascaris* eggs are occasionally found in host feces; such eggs are usually thin-shelled, elongated ovoid, and frequently asymmetrical, the albuminous covering present or absent. Otto (*83*), in examining 59,329 eggs of *A. lumbricoides*, noted that 15.9 percent were infertile.

In a series of measurements involving 50 eggs, length 68μ to 84μ, width 50μ to 76μ; according to Foster (*27*), length 56μ to 73μ, width 46μ to 56μ Egg usually unsegmented when oviposited and on appearance in feces; when embryo within shell is fully formed and molted, development apparently ceases until egg is swallowed by suitable host.

EMBRYO

Fully developed embryos (fig. 19, *G*), obtained by crushing several embryonated eggs, 235μ to 266μ long by 11μ wide; according to Ransom and Foster (*97*), 200μ to 300μ long by 13μ wide; body nearly uniform in diameter, anterior end with small knob composed of 1 dorsal and 2 subventral lips (fig. 19, *B*) a feature first pointed out by Stiles (*130*), lips surrounded by outer circle of 2 subdorsal and 2 subventral double papillae and 1 pair of lateral single papillae; an inner circle of papillae also present, composed of 1 pair of large papillae on each lip (fig. 19, *B*), 1 amphid present laterally on each subventral lip. Esophagus 95μ to 102μ long, occupying about one-third of entire length of worm. Intestine very granular, connecting posteriorly with a slender rectum. Genital primordium not visible in living specimens. Tail conical, usually pointing dorsad, 21μ to 25μ long; according to Ransom and Foster (*97*), 40μ long. Fully developed embryos are enclosed within a sheath (fig. 19, *G*) indicating that they have molted once while within the shell.

Development and Infectivity of Embryo

Although voluminous data are available in the literature on the development of *Ascaris* eggs, there are certain peculiarities in connection with the infectivity which are not yet understood. The references to "embryonated eggs" commonly found in the literature presumably refer to infective eggs, but observations of the writer indicate that the so-called "embryonated eggs" are not always infective. Apparently an egg is not infective until the embryo within the shell has undergone a first molt. The time required for this molt depends on the temperature at which the egg is incubated.

That larvae of *Ascaris* undergo a molt while in the egg has already been noted by Ransom and Foster (*97*); these writers do not specify, however, that the molt is essential before the egg is infective. They report that some eggs cultured by them at from 33° to 34° C. contained "fully developed embryos in 10 days", but they give no information to show that these eggs were actually infective. To obtain information on the development and infectivity of embryos of *A. suum*, the author made the following experiment:

A large number of *Ascaris* eggs obtained from the uteri of gravid females were cultured in Petri dishes in 1-percent formalin solution at various temperatures, namely, 22° to 24°, 30° to 33° C. When the

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eggs contained young embryos, such as is shown in figure 19, *F*, about 4,000 of the eggs were fed to 1 or 2 young guinea pigs weighing about 140 g each; feedings were continued thereafter daily until the eggs

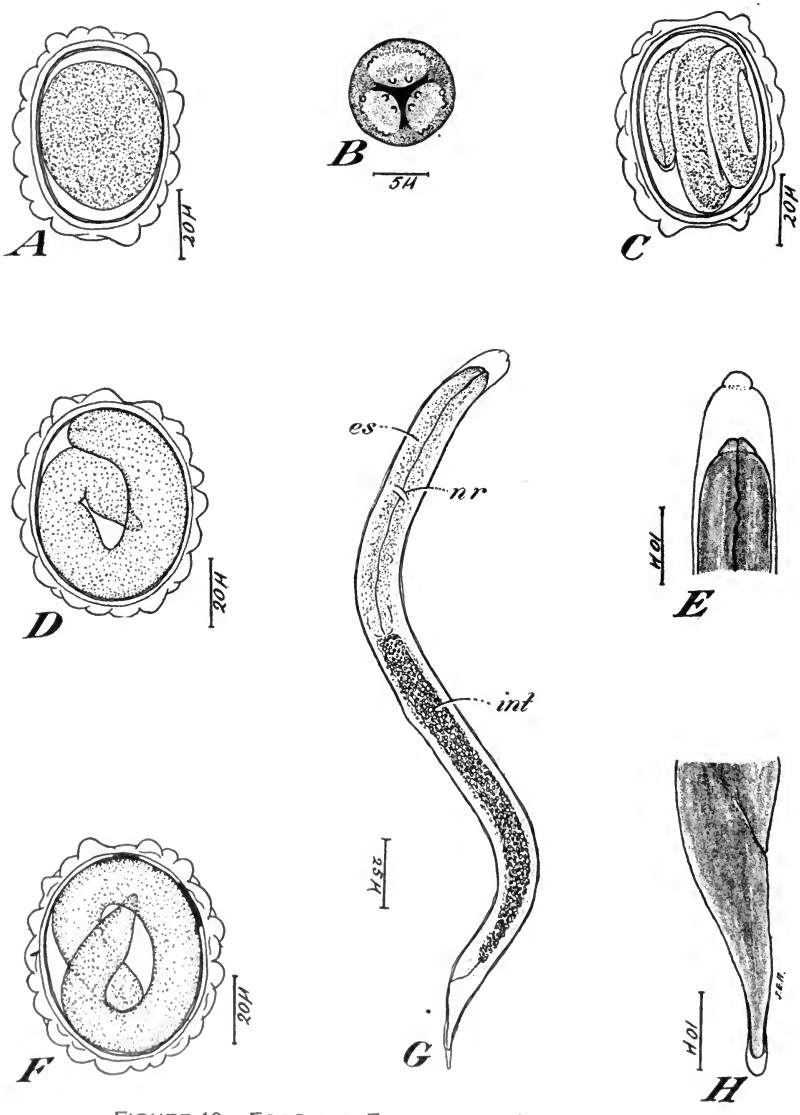

FIGURE 19.—EGGS AND EMBRYOS OF ASCARIS SUUM.

Egg: *A*, As found in freshly deposited feces of swine; *D*, containing young embryo; *F*, containing young embryo later in development; *C*, with an infective embryo.
Embryo: *B*, Fully developed, anterior end, en face view; *G*, infective embryo, obtained by crushing the eggshell, showing cuticle of first molt; *E*, anterior portion of infective embryo, side view; *H*, tail of embryo on verge of first molt.

fed contained embryos which had molted. Molting of the embryos was best observed by placing the eggs under a cover slip and then tapping the latter sharply with the handle of a dissecting needle until

most of the embryos became liberated from their shells. The guinea pigs were killed 5 days after feeding; the lungs were examined for gross lesions and were also chopped in small pieces and placed in a small Baermann apparatus. The results of the observation of the larvae cultured at 33° and of the feeding experiments are shown in table 18.

TABLE 18.—*Development and infectivity of eggs of Ascaris suum after incubation at 33° C.*

[Date of incubation, June 14, 1933]

Days after incubation (number)	Stage of egg development	Results of lung observations of guinea pigs 5 days after being fed *Ascaris* eggs [1]	Days after incubation (number)	Stage of egg development	Results of lung observations of guinea pigs 5 days after being fed *Ascaris* eggs [1]
0	1 cell		16	10 percent of embryos in first molt.	Several petechial hemorrhages; 5 *Ascaris* larvae recovered.
5	Morula				
10	Late tadpole				
12	Young embryo, as shown in figure 19, *F*.	No lesions or larvae.	17	50 percent of embryos in first molt.	Lungs moderately congested; 16 *Ascaris* larvae recovered.
13	do	Do.			
14	Apparently fully developed embryo.	Do.	18	90 percent of embryos in first molt.	Lungs heavily congested; 28 *Ascaris* larvae recovered.
15	do	Do.			

[1] Eggs not fed 0, 5, and 10 days after incubation.

Table 18 shows that eggs of *Ascaris suum* incubated at 33° C. contained fairly well-developed embryos in from 12 to 15 days after incubation (fig. 19, *F*), and that the eggs reached the infective stage at the time the embryos had molted (fig. 19, *G*), which was 16 days after incubation.

Eggs which were incubated at 30° and at 22° to 24° C. (room temperature) contained some molted embryos 18 and 28 days, respectively, after the cultures were made. Previous to the molting of the embryos, these eggs failed to produce lesions when fed to guinea pigs, and no larvae were recovered from the lungs; lesions and *Ascaris* larvae were noted, however, in the lungs of guinea pigs which were fed the eggs at the time the embryo began to molt.

TRICHURIDAE

TRICHURIS SUIS (SCHRANK, 1788) A. J. SMITH, 1908

(Fig. 20)

Synonyms.—*Trichocephalus suis* Schrank, 1788; *T. apri*, Gmelin, 1790; *T. crenatus* Rudolphi, 1809.

Hosts.—Swine, wild boar, and wild pig (*Sus bengalensis*).

Location.—Adults in cecum and colon.

Distribution.—Cosmopolitan.

DESCRIPTION OF EGG AND EMBRYO

EGG

Eggshell usually barrel shaped, thick, dark brown, and provided with a clear knob at each pole (fig. 20, *A*). In a series of measurements involving about 50 eggs, length 60μ to 68μ, width 28μ to 31μ; according to Hall (*41*), length 52μ to 56μ. Egg unsegmented when passed in feces. Development of embryo proceeds outside the host until embryo is fully formed; subsequently development apparently ceases until egg is ingested by suitable host.

EMBRYO

Fully formed embryos, obtained by crushing several embryonated eggs, 136μ to 163μ long by 11μ wide (fig. 20, *I–K*). Body tapering slightly at anterior and posterior portions; anterior end rounded, bearing a small lancet-shaped spear, the latter sometimes protruding from mouth cavity and sometimes retracted within cavity; spear connecting posteriorly with a small, slender, dark base. Fülleborn (*30*) has reported a similar spear and dark base in embryos of *Trichuris trichiura* and stated that this base, called by him "Lanzen-Schaft", is fixed to the digestive tract; when the embryo of *T. suis* is viewed laterally, the spear appears to lie slightly oblique to the longitudinal axis of body. Esophagus 60μ long, poorly defined, extending slightly less than one-half entire length of embryo; posterior to esophagus an undifferentiated mass of granules extending to posterior end of body, most of this representing the intestinal tract. Tip of tail ending in a characteristic rounded knob (fig. 20, *K*).

Development of the Embryo

The development of the embryo of *Trichuris suis* within the egg-shell is apparently dependent upon the environment. Considerable information is available with reference to the time necessary and other factors essential for development of the eggs of several species of *Trichuris*. Davaine (*23*) reported that *Trichuris* eggs isolated from feces of man and cultured in water required 8½ months to become embryonated. Railliet (*91*) noted that eggs of *Trichocephalus depressiusculus* (=*Trichuris vulpis*) required about 6 months to embryonate when cultured in water. According to Fülleborn (*29*), eggs of *Trichuris trichiura* cultured at 26° C. were embryonated in about 3½ weeks; Hasegawa (*45*) also found that some eggs of *T. trichiura* were embryonated in 28 days at from 28° to 30°. Cort and collaborators (*19, 20, 21*), in a field survey of helminthic infestation in southwestern Virginia, Panama, and China, noted that infestation with *T. trichiura* was high in regions where shade, warmth, and abundance of moisture prevailed; in some cases, however, where the incidence of *Trichuris* infestation was high, these investigators found that climatic and soil conditions were not the primary determining factors in the distribution of this parasite. Spindler (*122*) suggested that a considerable quantity of moisture was probably necessary for the development of the whipworm of man. The same writer (*123*), in a study of temperature and moisture requirements in the development of *T. vulpis*, found that eggs cultured in water at 30° became embryonated in 16 days, whereas those cultured at 37° became embryonated in from 12 to 15 days; eggs on wet soil and those in a saturated atmosphere at 22° and 30° developed normally, whereas on dry soil at 30°, 98 percent of the eggs failed to become embryonated and were no longer viable after 29 days. In field studies of the trichurid of man in Louisiana, Otto (*82*) concluded that heavy rains in addition to long warm seasons and shade proved ideal for optimum culture conditions of *Trichuris* eggs. Nolf (*80*) has also noted that the eggs of whipworms of man require highly saturated atmosphere for development of the embryo.

The writer obtained eggs of *Trichuris suis* from feces of a heavily infested pig and cultured them in water in an incubator at 37.5° and 33° C., and in charcoal and feces at room temperature (22 to 24°), and outdoors underground. The mean temperature in Washington, D. C., during the period of the outdoor experiment from March 16 to October 12, 1933, was as follows: March, 6.1° C.; April, 7.3°; May, 19.6°; June, 23.7°; July, 24.5°; August, 24°; September, 21.6°; October, 16°.

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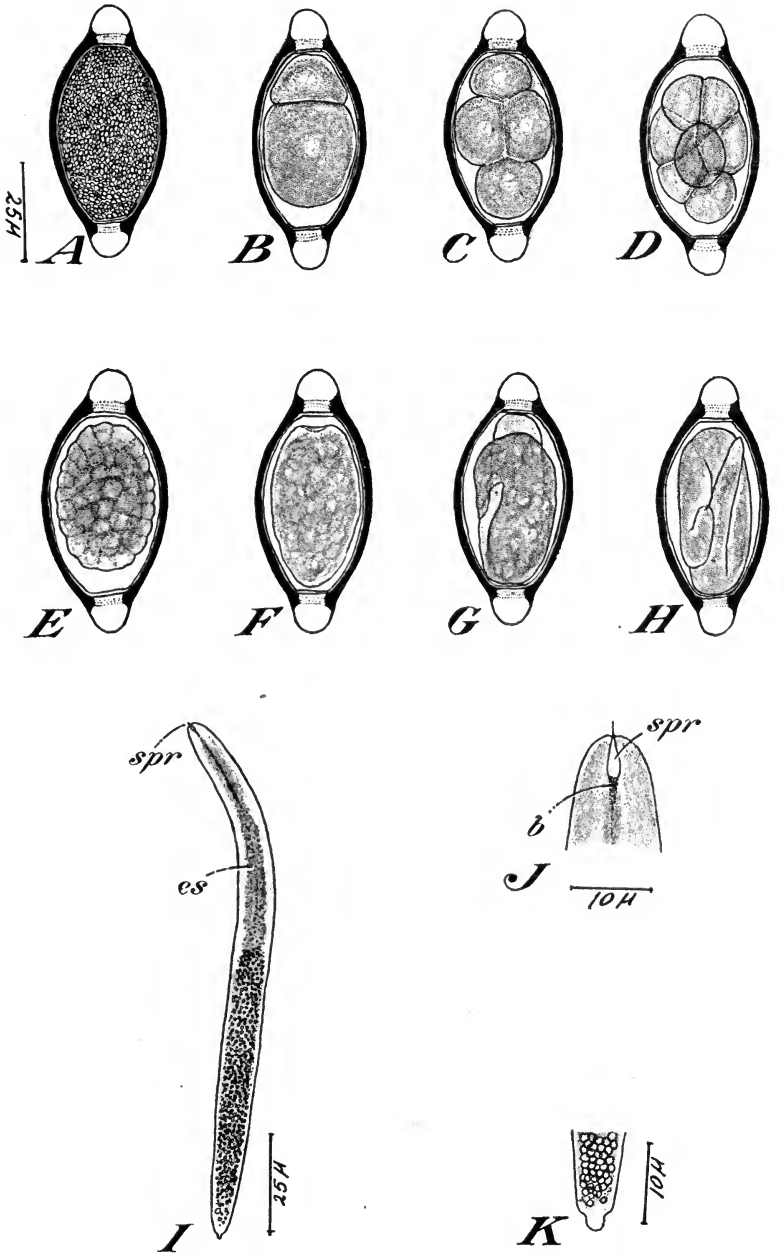

FIGURE 20.—EGGS AND EMBRYOS OF TRICHURIS SUIS.

Egg: *A*, As found in freshly deposited feces of swine; *B*, egg 1 day after incubation at 37.5° C.; *C*, 2 days after incubation at 37.5°; *D*, 5 days after incubation at 37.5°; *E*, 7 days after incubation at 37.5°; *F*, 12 days after incubation at 37.5°; *G*, 16 days after incubation at 37.5°; *H*, 18 days after incubation at 37.5°, with a fully developed embryo.

Embryo: *I*, Obtained by crushing the eggshell; *J*, anterior end of embryo; *K*, posterior end.

Eggs cultured in water were first isolated from pig feces by the method outlined by McCoy (*70*). The eggs were then placed in a small glass receptacle containing water to a depth of about 3 mm. In order to avoid excessive evaporation the receptacle was placed within a 100-cc beaker containing moistened cotton at the bottom. The beaker was then covered with a thick layer of cotton and placed in the incubator. The small glass receptacle containing eggs was removed from the incubator from time to time and the development of the eggs recorded.

For observations on the development of eggs at room temperature and outdoors, the hog feces containing trichurid eggs were mixed with animal charcoal up to one-third of the mass of feces. This mixture was slightly moistened with water and transferred to large specimen bottles about 12 cm high and 5 cm in diameter; the bottles were covered with a paper cap through which many minute openings were made. Specimen bottles containing the feces-charcoal mixture were kept at room temperature for observation, the bottles being placed under bell jars. Within each bell jar was placed a large culture dish containing water, the purpose of which was to keep the moisture content of the jar as high as possible. The bottom of the bell jar was raised above the surface of the table to a distance of about 2 mm in order to allow free air circulation. For observations on the development of eggs under outdoor conditions, the specimen bottles referred to were covered with aluminum caps in which several small openings were made; these bottles were then taken outdoors and placed upside down in sheltered areas about 2 inches underground. After the desired lapse of time, each bottle was removed, and eggs were recovered for examination by the salt-flotation method.

The results of the observations on the development of eggs and embryos of *Trichuris suis* are given in table 19.

TABLE 19.—*Stage of development of eggs of Trichuris suis in water and in feces-and-charcoal media*

[Date of incubation Mar. 16, 1933]

Days after incubation (number)	Stage of development of eggs, at indicated temperature, in—			
	Water		Charcoal-feces culture	
	37.5° C.	33° C.	22°–24° C.	6.1°–24.5° C.
0	1 cell	1 cell	1 cell	1 cell.
1	2 cells	do	do	
2	4 cells	do		
3		2 cells		
5	8 cells	4 cells		
7	Early morula	16 cells	1 cell	
9	Advanced morula	Early morula		
12	Early gastrula	Advanced morula		
16	Late tadpole	do	2 cells	1 cell.
18	Fully embryonated	Early tadpole		
20		Late tadpole		
22		20 percent fully embryonated.		
25		All fully embryonated	Early morula	
40			Advanced morula	
51			Late tadpole	1 to 2 cells.
54			30 percent fully embryonated.	
60			Majority fully embryonated.	1 to 8 cells.
128				Some in late morula.
183				Some in late tadpole.
210				10 percent fully embryonated.

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Table 19 shows that temperature is one of the important factors in the development of the embryo. Eggs cultured at 37.5° C. were embryonated in 18 days, whereas some eggs cultured at 33° were embryonated in 22 days. At room temperature (22° to 24°) some eggs became embryonated in about 54 days, and of those kept outdoors underground at temperatures of from 6.1° to 24.5° some eggs became embryonated in 210 days. It was also observed that whereas practically 100 percent of the eggs incubated at 33° and 37.5° became embryonated, about 30 percent of the eggs at lower temperatures appeared to be in the process of degeneration. The observation on the development of the eggs outdoors may give some clue as to what takes place under field conditions.

TRICHOSTRONGYLIDAE

HYOSTRONGYLUS RUBIDUS (HASSALL AND STILES, 1892) HALL, 1921

(Figs. 21–26)

Synonyms.—*Strongylus rubidus* Hassall and Stiles, 1892; *Haemonchus rubidus* (Hassall and Stiles, 1892) Sluiter and Swellengrebel, 1912; *Ostertagia rubida* (Hassall and Stiles, 1892) Travassos, 1918; *Trichostrongylus rubidus* (Hassall and Stiles, 1892) Fiebiger, 1923.

Hosts.—Swine and, experimentally, guinea pig.

Location.—Adults in stomach of host.

Distribution.—Asia (Philippine Islands), Europe (England, Germany, and Hungary), Central America (Panama), North America (United States).

Description of Egg, Embryo, and Preparasitic Larval Stages

EGG

Eggshell thin, transparent, and oval in shape, with poles usually unequal, one being less convex than the other (fig. 21, *A*). In a series of measurements involving about 50 eggs, length 60μ to 76μ, width 31μ to 38μ; according to Skrjabin and Bekensky (*121*), length 71μ to 78μ, width 35μ to 42μ. Egg containing an early tadpole-stage embryo when deposited with the feces of the host.

EMBRYO

Embryo, when ready to hatch, resembling first-stage larva; about 280μ to 300μ long by 17μ wide.

FIRST-STAGE LARVA

Shape and size.—Larva resembling corresponding stage of related strongyles; body slender and cylindrical for most of its length, tapering slightly anteriorly and more so posteriorly (fig. 21, *F*); anterior end with 6 minute elevations, possibly representing 2 subdorsal and 2 subventral papillae, and 2 lateral amphids (fig. 21, *C*); posterior portion terminating in a long, slender, pointed tail. Newly hatched larvae 290μ to 315μ long by 17μ wide; before molting, first-stage larvae attain a length of about 546μ to 554μ and a width of 22μ (table 20).

Cuticle.—Thin, transparent, and with very fine transverse striations.

Alimentary tract.—Oral opening leading into a cylindrical buccal cavity, 11μ to 15μ long. Esophagus rhabditoid, the anterior part, or corpus, separated from posterior bulb by a constriction, the isthmus; bulb possessing the usual Y-shaped valve; base of esophagus with cells representing primordium of esophageal intestinal valve. Intestine somewhat granular, composed of 8 dorsal and 8 ventral cells; nuclei of these cells alternating with one another, causing cells to bulge out into lumen of intestine, giving the latter a zigzag or serpentine appearance when viewed laterally; intestine connecting posteriorly with a fine slitlike canal about 15μ long, lined with a thin cuticularized membrane.

Nervous system.—Nerve ring appearing as a band encircling esophagus 75μ to 91μ from its anterior end; ring surrounded by several nuclei of nerve cells.

Excretory system.—Excretory pore opening ventrally 80μ to 95μ from anterior end.

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Genital primordium.—Represented by a small elliptical body, composed of 2 epithelial cells enclosing 2 germinal cells, 165μ to 275μ from anterior end, ventral in position, and near junction of fourth and fifth intestinal cells. As is pointed

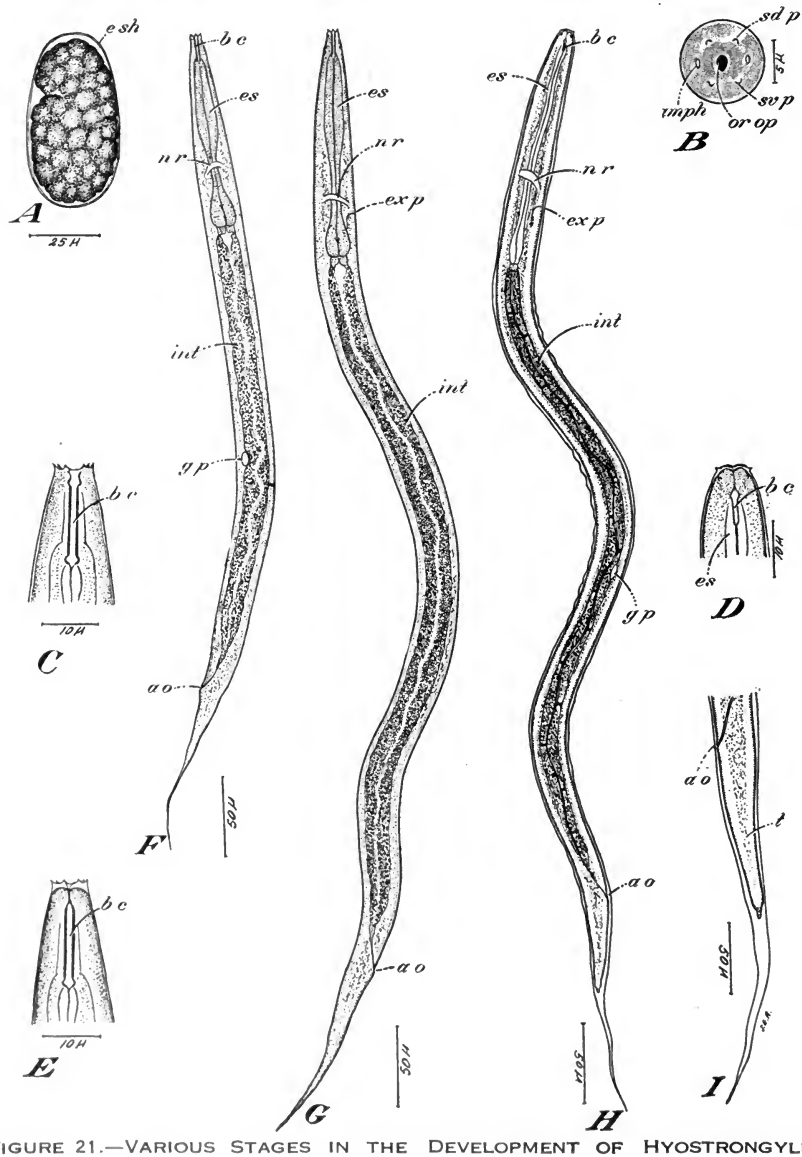

FIGURE 21.—VARIOUS STAGES IN THE DEVELOPMENT OF HYOSTRONGYLUS RUBIDUS.

First-stage larva: *C*, Anterior end; *F*, lateral view.
Second-stage larva: *E*, Anterior end, undergoing second molt, lateral view; *G*, lateral view of larva.
Third-stage larva: *B*, Anterior end, en face view; *D*, anterior portion showing shape of buccal cavity; *H*, lateral view of larva; *I*, tail.

out later, the sex of some specimens of *Hyostrongylus rubidus* can be determined in this stage.

Table 20 shows the rate of development of first-stage larvae of *Hyostrongylus rubidus* in water-charcoal feces media at room tem-

perature (22° to 24° C.), the measurements having been made at different periods after the preparation of the cultures.

TABLE 20.—*Principal measurements of 5 first-stage larvae of Hyostrongylus rubidus at various periods of development*

Item	Period of development and measurements of larva no.—				
	1	2	3	4	5
Period of development.....hours	2	2	50	[1]74	[1]74
Length of body.....microns	290	315	436	546	554
Maximum width of body.....do	17	17	19	22	22
Length of buccal cavity.....do	11	11	15	15	15
Length of esophagus.....do	87	87	95	117	110
Distance of nerve ring from anterior end.....do	75	75	-------	91	87
Distance of excretory pore from anterior end.....do	80	82	-------	95	-------
Distance of genital primordium from anterior end.....do	170	165	255	265	275
Length of tail.....do	75	80	105	121	125

[1] Larva undergoing first molt.

SECOND-STAGE LARVA

Shape and size.—Second-stage larva similar in shape to larva of first stage (fig. 21, *G*). In this stage the larvae grow considerably, and before the second molt attain a length of about 702μ to 748μ and a width of 26μ (table 21).

Cuticle.—With fine transverse striations.

Alimentary tract.—Buccal cavity as in first-stage larva, but in the transition to the next stage, anterior portion of lumen narrowing gradually (fig. 21, *E*); ultimately one-half of original lumen left open posteriorly, lumen of buccal cavity then being shaped like a spearhead. Esophagus rhabditiform, 117μ to 133μ long; intestine as in first-stage larva.

Nervous system.—In general, as in first-stage larva; nerve ring 97μ to 106μ from anterior end.

Excretory system.—Excretory pore 102μ to 117μ from anterior end.

Genital primordium.—During most of second larval stage, composed of group of 4 cells as in first stage; during transition to third stage, epithelial cells increasing to about 10 or 11 in number.

Table 21 shows the rate of development of second-stage larvae of *Hyostrongylus rubidus* in water-charcoal-feces media at room temperature (22° to 24° C.), the measurements having been made at different periods after preparation of the culture.

TABLE 21.—*Principal measurements of 5 second-stage larvae of Hyostrongylus rubidus at various periods of development*

Item	Period of development and measurements of larva no.—				
	1	2	3	4	5
Period of development.....hours	85	98	98	[1]122	[1]122
Length of body.....microns	577	624	670	702	748
Maximum width of body.....do	24	24	26	26	26
Length of buccal cavity.....do	15	15	15	15	15
Length of esophagus.....do	117	125	129	133	133
Distance of nerve ring from anterior end.....do	-------	106	102	97	102
Distance of excretory pore from anterior end.....do	102	-------	-------	106	117
Distance of genital primordium from anterior end.....do	275	-------	285	357	368
Length of tail.....do	129	114	129	127	136

[1] Larva undergoing second molt.

THIRD-STAGE LARVA

Shape and size.—Body similar in shape to that of previous stage, but more slender (fig. 21, *H*), head surrounded by outer circle of 2 subdorsal and 2 subventral papillae, and 2 lateral amphids (fig. 21, *B*); tail conical and shorter than that of previous stages, ending in a characteristic short digitiform process (fig. 21,

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I). Due to reduction in size of tail, third-stage larva shorter than some larvae of previous stage, those of third stage being 715μ to 735μ long by 22μ wide (table 22).

Cuticle.—With prominent transverse striations.

Alimentary tract.—In en face view, oral opening oval, being slightly elongated dorsoventrally (fig. 21, *B*). Mouth aperture leading into a narrow lumen connecting posteriorly with a characteristic spearhead-shaped cavity about 8μ long

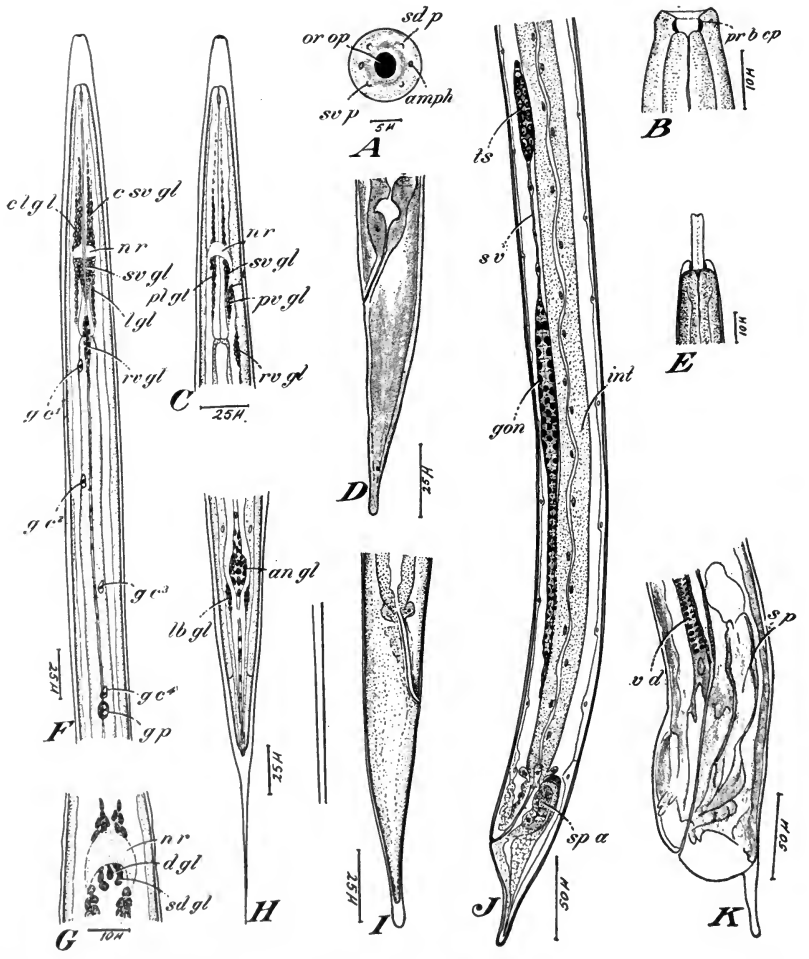

FIGURE 22.—THIRD- AND FOURTH-STAGE LARVAE OF HYOSTRONGYLUS RUBIDUS.

Third-stage larva: *C*, Anterior portion, lateral view; *F*, anterior half showing general features of nervous system and position of giant cells, ventral view; *G*, region of nerve ring, dorsal view; *H*, posterior portion of larva, ventral view.

Fourth-stage larva: *A*, Anterior end, en face view; *B*, anterior portion showing provisional buccal capsule; *E*, anterior portion of larva undergoing fourth molt; *D*, tail of female; *I*, tail of female undergoing fourth molt; *J*, posterior portion of male showing development of genitalia; *K*, posterior portion of male undergoing fourth molt.

representing remains of buccal cavity of previous stage (fig. 21, *D*). Esophagus strongyliform, more slender than in that of previous larval stages, and 130μ to 148μ long. Intestine composed of 8 dorsal and 8 ventral cells, and less granular than that of previous larval stages; posteriorly, intestine connecting with a slender rectal canal.

Nervous system.—Closely related to that of other strongyles, such as *Ancylostoma duodenale*, *Haemonchus contortus*, *Trichostrongylus instabilis*, and *T. douglasi*, described by Looss (*67*), Veglia (*135*), Mönnig (*76*), and Theiler and Robertson

(*134*), respectively. In stained specimens, nerve ring appearing as a light band surrounding the esophagus, 97μ to 106μ from anterior end. Anterior to nerve ring, 6 papillary nerves, of which 2 subventral, 2 subdorsal, and 2 lateral (fig. 22, *C*, *F*, *G*). Posterior to nerve ring, 2 lateral ganglia extending almost to base of esophagus; a group of ventral nuclei, posterior to nerve ring, probably corresponding to cells of subventral ganglion; posterior to nerve ring, a dorsal and a subdorsal ganglion. The posteroventral ganglion apparently represented by the group of nuclei of cells surrounding excretory canal; retrovesicular ganglion slightly posterior to posteroventral ganglion and at level of base of esophagus; the 2 lumbar ganglia located near region of anus (fig. 22, *H*).

Excretory system.—Excretory pore, 117μ to 125μ from anterior end; excretory pore connected with a canal leading backward and becoming indistinguishable in passing between cells of nervous system.

Genital primordium.—Location as in previous stages; 368μ to 395μ from anterior end; primordium composed of a group of about 12 or 13 cells, 2 of these germinal cells and the others epithelial cells. A further discussion of the genital primordia of this and other larval stages is given on page 59.

Table 22 gives the measurements of third-stage larvae of *Hyostrongylus rubidus*.

TABLE 22.—*Measurements of 5 third-stage larvae of Hyostrongylus rubidus* [1]

Item	Period of development and measurements of larva no.—				
	1	2	3	4	5
Period of development ..... days	7	7	7	7	7
Length of body ..... microns	715	717	717	720	735
Maximum width of body ..... do	22	22	22	22	22
Length of esophagus ..... do	135	135	148	135	130
Distance of nerve ring from anterior end ..... do	106	102	102	97	106
Distance of excretory pore from anterior end ..... do	123	117	121	123	125
Distance of genital primordium from anterior end ..... do	368	370	382	370	395
Length of tail ..... do	68	64	60	64	68

[1] Measurements do not include sheath.

DIFFERENCES IN FIRST THREE STAGES

The outstanding differential features of the first three larval stages of *Hyostrongylus rubidus* are as follows:

First-stage larva.—Buccal cavity long, with parallel rod-shaped walls, opening directly to the exterior; esophagus rhabditiform; tail long and pointed. Larva 290μ to 554μ long by 17μ to 22μ wide.

Second-stage larva.—Buccal cavity, esophagus, and tail as in first-stage larva. Larva 577μ to 748μ long by 24μ to 26μ wide.

Third-stage larva.—Buccal cavity short, spearhead-shaped, and opening anteriorly by a narrow lumen; esophagus strongyliform; tail short and conical, terminating in a small digitiform process. Larva 715μ to 735μ long by 22μ wide.

DEVELOPMENT OF PREPARASITIC LARVAL STAGES

The method of obtaining eggs and studying the various developmental stages was in some respects similar to that described by Schwartz (*108*) in connection with a study of the preparasitic development of *Monodontus phlebotomus* (=*Bustomum phlebotomum*). The eggs were obtained by cutting up gravid females of *Hyostrongylus rubidus*, which liberated most of the eggs from the uteri. In order to separate the eggs from the fragments of tissue, the chopped-up worm material was put in a sieve of fine mesh placed over a small porcelain dish, and a gentle stream of water was played on it. The

water passing through the filter carried most of the eggs into the porcelain dish. This water was then centrifuged, and the eggs recovered from this sediment were placed in two small Petri dishes. In one dish was put just enough water to cover the bottom, and in the other dish was put a small quantity of large granules of washed animal charcoal to which were added about 3 drops of filtrate from boiled hog feces. The dish containing only water served for noting the development of the eggs and to obtain first-stage larvae for morphological study; the other dish containing charcoal-and-feces medium served for noting the development of first-, second-, and third-stage larvae and to enable the writer to study the morphology and process of development of these larvae. The reason for using small quantities of water in these cultures was that in a large quantity of water larvae would disintegrate before reaching the second or third stage.

At the time of their removal from the uteri of female worms, eggs were in most cases in a well-advanced morula stage, though the range in development was from one cell to the early tadpole stage. At room temperature (22° to 24° C.), the majority of eggs contained coiled and moving embryos after a period of 24 hours. Hatching was observed 39 hours after incubation. Newly hatched larvae moved very slowly, but as they began to feed they became active and moved in a series of wriggling jerks. The period of activity and growth was followed by the first lethargus, during which the larvae were inactive and began to shed their first cuticle. The first lethargus was observed 103 hours after incubation, and complete shedding of the cuticle occurred 10 hours later. Second-stage larvae moved even more actively than those of the previous stage. This period of activity was again checked by the second lethargus, which occurred 161 hours after eggs were placed in culture; 7 hours later ensheathed or third-stage larvae were seen moving actively in the dish.

Third-stage larvae of *H. rubidus* wriggled very actively in serpentine movements. Another peculiarity noted was the attempt of these larvae to rise when in water; if a small Petri dish half full of water and containing larvae was slightly agitated, the larvae would be quickly carried up by the water currents and would be seen swimming upward for a considerable period, the anterior end of a larva during this time being very close to the surface of the water. The writer has found this peculiarity very helpful in differentiating these larvae from those of other strongyle larvae encountered in hog feces.

The following tabulation shows the time required for the development of larvae to the third stage in a moist charcoal-and-feces medium at room temperature (22° to 24° C):

Hours after incubation	*Degree of development*
0	1-cell to early tadpole stage.
24	Most eggs embryonated.
39	Eggs hatching.
65	Few larvae in first stage.
89	Majority of larvae in first stage.
103	First lethargus in progress.
113	Few larvae in first molt.
124	Few larvae in second stage.
137	Majority of larvae in second stage.
161	Second lethargus in progress.
168	Larvae in second molt (=third stage).

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Development of Parasitic Stages in Final Host

As already reported by the writer (7), infective larvae of *Hyostrongylus rubidus* develop to maturity in the stomachs of guinea pigs. These animals were used throughout the investigation on the parasitic stages of *H. rubidus*. Young guinea pigs weighing between 130 and 150 g were used; these animals were kept without feed for about 24 hours before they were fed third-stage larvae of *Hyostrongylus*.

In guinea pigs fed ensheathed third-stage larvae and killed 15 minutes after infection, the larvae had exsheathed and were adherent to the mucosa of the stomach; this observation was made by first washing the contents of the stomach and then examining the scrapings of its inner lining. These larvae were found to remain in the stomach

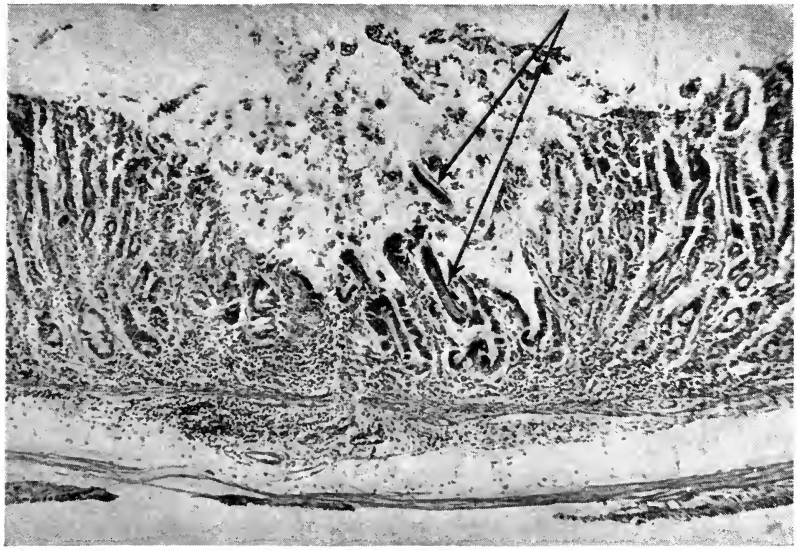

FIGURE 23.—Cross section of stomach of guinea pig, showing *Hyostrongylus rubidus* worms (indicated by arrows) and erosion of the gastric epithelium.

and to develop to maturity there without any extensive migration in the tissues of the host, as in the case of the hookworm and some other strongyle larvae. In the process of development the larvae penetrated the epithelial folds of the mucosa and frequently caused ulceration of gastric glands and blood vessels (fig. 23); large masses of coagulated blood have been found in the stomach contents of such guinea pigs.

As shown in table 23, the rate of development of male and female third- and fourth-stage larvae in the final host is approximately the same. Some larvae of both sexes were found in the third molt 5 days after experimental infection, and larvae which had completely shed the third cuticle were noted 3 and 4 days later. Fourth-stage larvae of both sexes were noted undergoing the fourth or final molt 13 days after experimental infection (fig. 22, *E*, *I*, and *K*). Completely formed adult males and females were noted 17 and 19 days, respectively, after experimental infection. The outstanding morphological features during the development of third- and fourth-stage larvae in the final host are as follows:

Third-stage larvae.—Larvae grow in size, and at the time of the third molt male larvae attain a length of 925μ to 1.12 mm (table 23); the genital primordia have undergone considerable differentiation, the primordia of the future testis and ducts being recognizable (fig. 24, *K*). At this stage female larvae have also increased in size, and at the time of the third molt are about 889μ long (table 23); the female genital primordia have also undergone considerable differentiation, the primordia of the ovary and ducts being recognizable (fig. 26, *I*).

Fourth-stage larvae.—These larvae have a provisional buccal capsule (fig. 22, *B*). Male larvae are 1.38 to 3.1 mm long by 30μ to 60μ wide; the tail, which will form the future bursa, becomes distended (fig. 22, *K*); the primordium of the vas deferens is connected with the rectum. Female larvae are 1.01 to 3 mm long by 26μ to 45μ wide; the genital primordium is definitely attached to the body wall ventrally and the future vulva is recognizable. Further discussion of the development of the genital primordium of the larval stages is given on page 59. Table 23 shows the development of *Hyostrongylus rubidus* in a final host (guinea pig), the measurements having been made on different days after experimental infection.

TABLE 23.—*Principal measurements of third- and fourth-stage larvae and adult (fifth-stage) Hyostrongylus rubidus in various periods of development in the guinea pig*

Item	MALES									
	Period of development and measurements of—									
	Third-stage larva no.—				Fourth-stage larva no.—				Adult (fifth stage) no.—	
	1	2	3	4	1	2	3	4	1	2
Period of development.....days	2	5	[1] 5	[1] 6	9	9	13	[2] 13	17	19
Length of body.....microns	740	820	925	1,123	1,388	1,440	2,100	3,100	3,800	4,900
Maximum width of body.....do	22	22	26	30	30	38	40	60	60	65
Length of esophagus.....do	155	197	228	220	288	281	326	539	524	539
Distance of nerve ring from anterior end.....microns	106	110	110	121	141	148	150	174	197	197
Distance of excretory pore from anterior end.....microns	125	125	136	144	172	180	178	258	258	281
Distance of cervical papillae from anterior end.....microns	.....	.....	.....	.....	.....	.....	.....	.....	273	281
Distance of genital primordium from posterior end.....microns	355	350	315	310	.....	.....	.....	.....	.....	.....
Length of spicules.....do	.....	.....	.....	.....	.....	.....	.....	114	121	114
Length of gubernaculum.....do	.....	.....	.....	.....	.....	.....	.....	55	57	57
Length of tail.....do	72	75	72	83	72	72	72	.....	.....	.....
	FEMALES									
Period of development.....days	2	3	5	[1] 5	8	8	9	[2] 13	19	21
Length of body.....microns	742	795	811	889	1,014	1,404	1,528	3,000	4,800	8,000
Maximum width of body.....do	22	22	22	22	26	30	30	45	68	106
Length of esophagus.....do	158	200	212	220	258	288	288	440	530	608
Distance of nerve ring from anterior end.....microns	106	110	106	114	110	121	125	170	190	220
Distance of excretory pore from anterior end.....microns	123	125	129	135	140	148	163	205	266	234
Distance of cervical papillae from anterior end.....microns	.....	.....	.....	.....	.....	.....	.....	.....	296	315
Distance of genital primordium from posterior end.....microns	330	250	200	159	.....	.....	.....	.....	.....	.....
Distance of genital opening from posterior end.....microns	.....	.....	.....	.....	220	273	286	532	920	1,372
Length of tail.....do	68	72	78	76	76	83	89	106	129	152

[1] Larva undergoing third molt.

[2] Larva undergoing fourth molt.

Sex Differentiation of Preparasitic Larvae and General Development of Primary Reproductive Organs

Although sexual dimorphism in the preparasitic larval stages of strongyles has not been reported previously, so far as the writer can ascertain, such differentiation has been noted in early stages of free-living nematodes and in spirurid larvae. Maupas (*74*) found that in third-stage larvae of *Rhabditis causaneli* the genital primordium was composed of a long cylindrical body in the center of which was a group of small cells which gave rise to the uterus and the oviduct in the fourth stage. Pai (*86*), in studying the life cycle of *Anguillula aceti*, noted sex differentiation, based apparently on differences in size of the early larval forms. Pai does not specify sex in the larval stages, but states that in newly hatched larvae the genital primordium of the 2 sexes appeared identical; in larvae 2 or 3 days old the morphological features of the male and female sex primordia appeared different. Pai also mentions that the female worms of *A. aceti* reached sexual maturity in 6 or 7 days, whereas the males reached this condition in 9 days. Seurat (*118*, *119*) pointed out that third-stage larvae of *Gongylonema scutatum* (=*G. pulchrum*) which later developed into females already showed the genital primordium attached to the body wall in the third stage. The writer has confirmed Seurat's observation and has also noted a similar attachment of the genital primordium in third-stage larvae of two other spirurids, *Physocephalus sexalatus* and *Ascarops strongylina*. The male genital primordium in these cases is not attached to the body wall but lies in the ventral region between the body wall and the intestine. Yokogawa (*137*), in his observation on larval development of *Heligmosomum muris* (=*Nippostrongylus muris*), could distinguish sex in third-stage larvae soon after they entered the host. Yokogawa's bases for sexual differentiation were: (1) The posterior migration of the genital primordium in larvae that develop to females; (2) structural differences in the caudal region in the 2 sexes; and (3) differences in the shape of the genital primordia in the 2 sexes. As is shown later, all these changes have been noted by the writer in the parasitic third-stage larvae of *Hyostrongylus rubidus*, but sexual dimorphism has also been noted in the preparasitic stages of these larvae.

According to observations by the writer, sex in preparasitic larval stages of *H. rubidus* may be determined by the position of a large nucleated cell, referred to later as the genital giant cell, close to the genital primordium. A cell apparently similar to this one was mentioned by Looss (*67*) as occurring in larvae of *Ancylostoma duodenale*, and by Mönnig (*76*) in larvae of *Trichostrongylus instabilis* and *T. rugatus*, and was also figured by the writer (*5*) in larvae of *Obeliscoides cuniculi*.

On several occasions, while studying stained specimens of third-stage larvae of *H. rubidus*, the writer observed that the genital giant cell was sometimes anterior to the genital primordium and sometimes lateral or posterior to it. Studies of the parasitic stages of the third and fourth stages of this parasite indicated that larvae having the genital giant cell anterior to the genital primordium developed to males, and those having the genital giant cell lateral or posterior to the genital primordium developed to females. The general development of the male and female genital systems and the probable significance of the genital giant cell are discussed later.

In a recent abstract, the writer (*8*) pointed out that the genital giant cell has been found to be the posterior cell of a group of 4 giant cells situated in the body cavity approximately equidistant from one another and for the most part ventral to the intestine (fig. 22, *F*). Each of these giant cells is about 5μ to 8μ long by 3μ to 6μ wide and is the primordium of each of 4 giant cells found in the body cavity of the adult worms. Four similar giant cells have been reported by Looss (*67*) in third-stage larvae of *Ancylostoma duodenale* and are referred to by him as "cells of unknown significance."

In the study of the detailed organization of the genital primordium the writer used Looss's (*67*) method, which consisted of staining the larvae with acid carmine. This stain brings out the structural details which are described in the following paragraphs:

MALES

First-stage larva.—Genital primordium of *Hyostrongylus rubidus*, like that described for several nematode larvae of first stage, composed of 4 cells, of which 2 are epithelial cells enclosing the other 2, which are germinal cells; in newly hatched larvae, the group of 4 cells is arranged at right angle to main axis of body (fig. 24, *A*). As larva becomes older during this stage, genital primordium rotates almost 90° to lie parallel with body wall (fig. 24, *B* and *C*); at the time genital primordium has rotated about 90°, genital giant cell lies anterior and close to genital primordium. Position of this giant cell usually differentiates male from female; in what are considered female first-stage larvae, genital giant cell lateral to genital primordium; in male larvae giant cell anterior to genital primordium. In early first-stage larvae giant cell, in some cases, slightly lateral and slightly anterior to genital primordium; in these transitional cases, impossible at present to differentiate sex. In late first-stage larvae, location of giant cell appears to be more nearly constant, either anterior to genital primordium in male larvae, or lateral to genital primordium in female larvae.

Second-stage larva.—Genital primordium during most of this stage composed of 2 germinal cells and 2 epithelial cells, corresponding to that of late first-stage larva. At time of transition to third stage, epithelial cells of genital primordium increase by cell division to about 11, whereas the 2 germinal cells do not divide. Genital giant cell still remains anterior and usually close to genital primordium (fig. 24, *D* and *E*).

Third-stage larva (preparasitic).—Genital primordium composed of about 11 epithelial cells surrounding 2 germinal cells (fig. 24, *F*), located 325μ to 343μ from posterior end; genital giant cell still anterior to genital primordium.

Third-stage larva (parasitic).—In larvae 48 hours after infection, most epithelial cells of genital primordium rearranged so that the two germinal cells lie in posterior portion of epithelial-cell group (fig. 24, *G*). Genital giant cell still anterior and close to genital primordium, which is 355μ to 360μ from posterior end of larva. Four days after experimental infection, epithelial cells of genital primordium increasing in size, apparently accompanied by movement of entire genital primordium directed toward changing ends and reversing original position of structure (fig. 24, *I* and *J*). In 5 or 6 days after infection, in late phase of third stage, genital primordium has completely reversed former position (fig. 24, *K* and *L*); during this rotation no division of either epithelial or germinal cells observed. At this time genital primordium shows somewhat definite differentiation; anterior portion containing germinal cells represents primordium of testis; "neck" region, composed usually of three epithelial cells, destined to form seminal vesicle; posterior portion, also epithelial in nature, is primordium of male gonoduct. Genital primordium 310μ to 315μ from posterior end. Reversal of position of male genital primordium in *H. rubidus* resembles similar rotation of male genital primordium of developing larvae of *Anguillula aceti*, a free living nematode, as determined by Pai (*86*). In *H. rubidus*, genital giant cell up to third molt is still anterior to genital primordium (fig. 24, *L*).

Fourth-stage larva and adult.—In 9 to 11 days after infection larva shows further differentiation of various genital structures (fig. 24, *M* and *N*), and further cell division, involving both epithelial and germinal cells (fig. 22, *J*). Genital giant cell far removed from anterior portion of genital primordium and slightly more anterior to latter (fig. 24, *O*) than in third-stage larva. Entire genital primordium

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during early part of this stage grows considerably in length, and by the thirteenth day after infection its long and slender posterior portion becomes united with the rectum; when the vas deferens shows definite connection with the rectum,

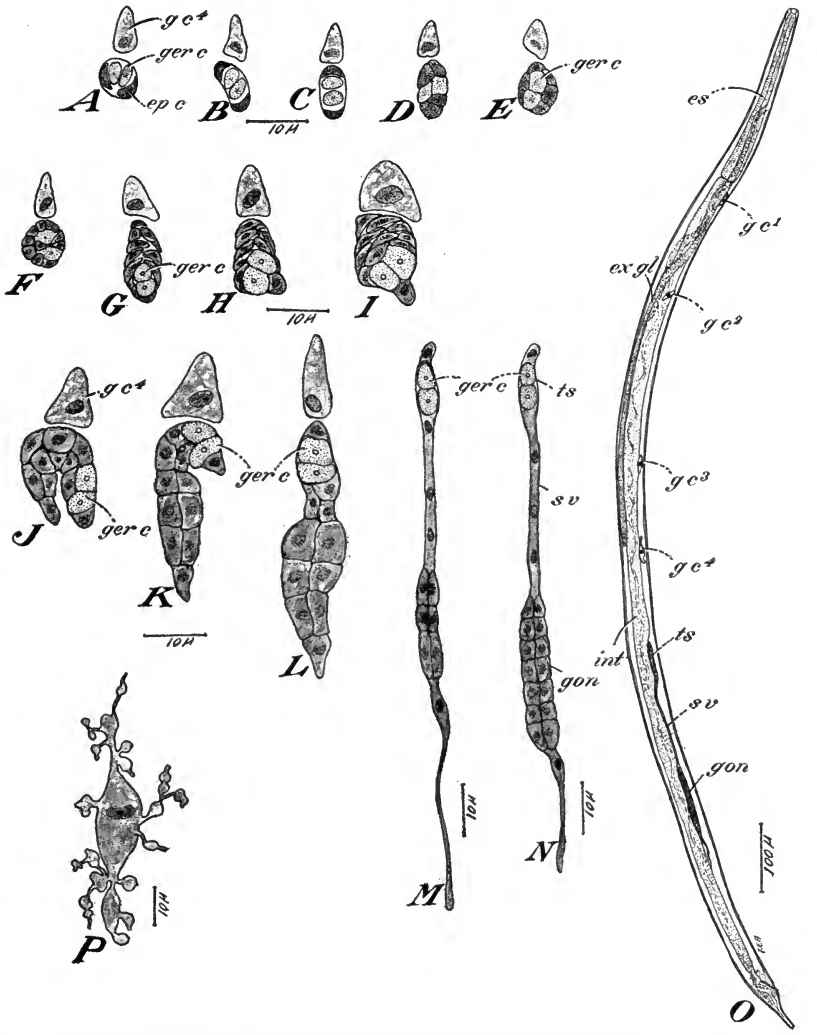

FIGURE 24.—PHASES IN THE DEVELOPMENT OF THE MALE GENITALIA AND POSITION OF THE GENITAL GIANT CELL IN HYOSTRONGYLUS RUBIDUS.

Genital primordium of first-stage larva: *A*, Of a newly hatched larva; *B*, of a larva a few hours after hatching; *C*, of a larva several hours after hatching.

D and *E*, Genital primordium of second-stage larva at time of second molt.

Genital primordium of third-stage larva: *F*, Of a preparasitic larva; *G*, of a larva recovered from a guinea pig 2 days after experimental infection; *H*, *I*, and *J*, of larvae recovered from a guinea pig 4 days after experimental infection; *K*, of a larva recovered from a guinea pig 5 days after experimental infection; *L*, of a larva recovered from a guinea pig 6 days after experimental infection (larva undergoing third molt).

M and *N*, Differentiation of testis and gonoduct of fourth-stage larvae 9 and 11 days, respectively, after experimental infection (genital giant cell not shown).

O, Fourth-stage male larva 11 days after experimental infection showing position of the four giant cells and genitalia.

P, Giant cell and its proliferations in body cavity of a young fifth-stage female worm.

larva begins to discard fourth or last larval cuticle (fig. 22, *K*); various portions of genitalia, corresponding to those of adult (fig. 25, *E*), now easily differentiated. Adult genital system (fig. 25, *E*) similar to that of related strongyles, consists

of an anterior portion, the testis, followed by the seminal vesicle, a thin- and transparent-walled tube containing three nuclei, followed in turn by the gonoduct which connects with the rectum. At center axis of testis there appears to be a

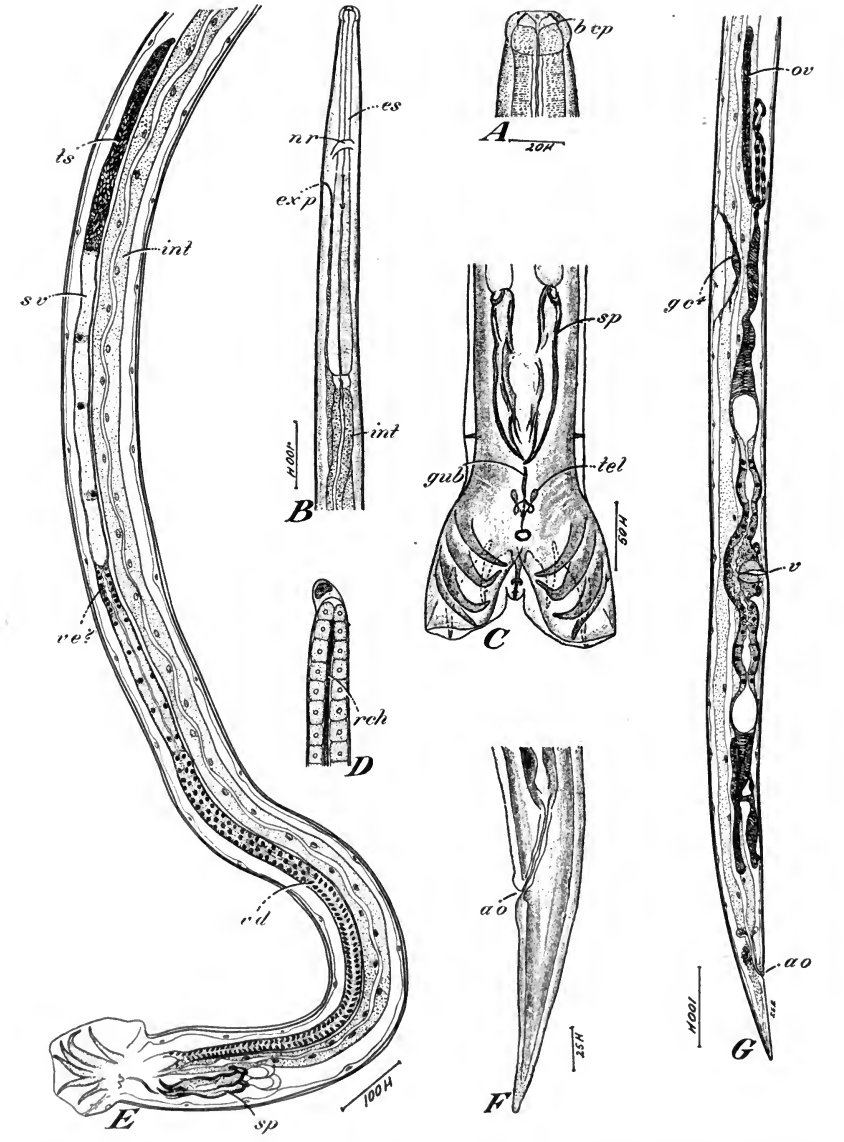

FIGURE 25.—YOUNG ADULT WORMS (FIFTH STAGE) OF HYOSTRONGYLUS RUBIDUS.

A, Anterior end of male; *B*, anterior portion of female; *C*, posterior portion of male showing spicules and bursa; *D*, anterior portion of testis, showing rachis; *E*, posterior portion of male showing genitalia; *F*, tail of female, lateral view; *G*, posterior portion of female, showing genitalia.

slender and solid longitudinal core from which radiate the germinal cells; this core probably corresponds to the rachis (fig. 25, *D*), a structure which has been mentioned by several writers as occurring in *Ascaris lumbricoides*, *Strongyloides* from sheep according to Rovelli (*103*), *Pseudalius inflexus* according to List (*64*), and other nematodes.

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The fate of the giant cells in the adult *Hyostrongylus rubidus* is discussed below.

FEMALES

First-stage larva.—Genital primordium of first-stage larva composed, as in male, of 2 epithelial cells and 2 germinal cells (fig. 26, *A*); in position and arrangement these cells similar to those of corresponding male first-stage larva. In somewhat late female first-stage larva, genital giant cell slightly lateral to genital primordium; in some early first-stage larva, as already mentioned, giant cell slightly anterior to genital primordium; in such cases sex of larva cannot be ascertained.

Second-stage larva.—Cells of genital primordium similar in number and position to those in second-stage male larva; giant cell usually lateral to genital primordium.

Third-stage larva (preparasitic).—Genital primordium composed of about 10 epithelial cells enclosing 2 germinal cells (fig. 26, *B*); in position, this developing organ corresponds to that of third-stage larva of male, being located 320μ to 338μ from posterior end. Genital giant cell usually lateral (fig. 26, *B*), and sometimes slightly posterior to genital primordium (fig. 26, *C*).

Third-stage larva (parasitic).—In 48 hours after infection, epithelial and germinal cells have become rearranged, so that germinal cells are one at each end of genital primordium (fig. 26, *D*), which has migrated slightly and is more posterior than in corresponding male larva; in female, genital primordium 330μ to 340μ from posterior end. Genital giant cell usually lateral to genital primordium; unlike that of male, female genital primordium does not reverse position but simply elongates anteriorly and posteriorly, carrying along at each end one germinal cell. In 4 days after infection, slight constriction at middle portion of genital primordium (fig. 26, *H*); in 5 days after infection, genital primordium has migrated farther posteriorly than that of corresponding male larva, primordium in female being 200μ from posterior end. At time of third molt genital primordium 159μ from posterior end and on verge of attachment to ventral side of body wall (fig. 26, *I*).

Fourth-stage larva and adult.—Genital primordium in general same as in previous stage, except that there is a multiplication of epithelial and germinal cells (fig. 26, *K*); it also becomes definitely attached to body wall as a result of proliferation of cells of body wall which connect with those of genital primordium (fig. 26, *J*). Genital giant cell has been found during fourth stage near end of anterior ovarian primordium (fig. 26, *L*); in young adult this cell not far from primordium of anterior uterine duct (fig. 25, *G*); soon becomes remote from ovary because latter grows anteriorly and extends as far forward as posterior portion of esophagus.

The four giant cells in the adult specimens of *Hyostrongylus rubidus* are not regularly arranged but are placed more or less equidistant from one another throughout the anterior half of the worm. Each of these giant cells in the adult worm is somewhat elongated dorsoventrally and sends off several branches from its periphery (fig. 24, *P*). In shape these giant cells resemble cells figured by Nassonov (*79*) in the body cavity of *Strongylus paradoxus* (=*Metastrongylus elongatus*) and referred to by him as the "phagocytic organ." Other stellate or branching structures have been reported in the body cavity of nematodes, notably by Bojanus, cited by Schneider (*105*), Bastian (*10*), Shipley (*120*), Hamann (*44*), and Looss (*65*).

The close association of one of these giant cells with the genital primordium indicates that it might have some relation to the genital system. Chitwood and Chitwood (*16*), in studying the anatomy of the adult *Cephalobellus papilliger*, have found in its body cavity two-celled structures referred to by them as "x-bodies", which are associated with the gonads. They expressed the opinion that these x-bodies might function as endocrine glands. Since little is known about such cells in the body cavity of nematodes, the writer is not

certain whether the giant cells in *Hyostrongylus rubidus* represent phagocytic cells or x-bodies, and whether or not these cells have any connection with the genital system.

In connection with the study of sex differentiation in stained specimens of *H. rubidus*, the male third-stage larvae appeared to be more numerous than the females. An actual count of 100 third-stage

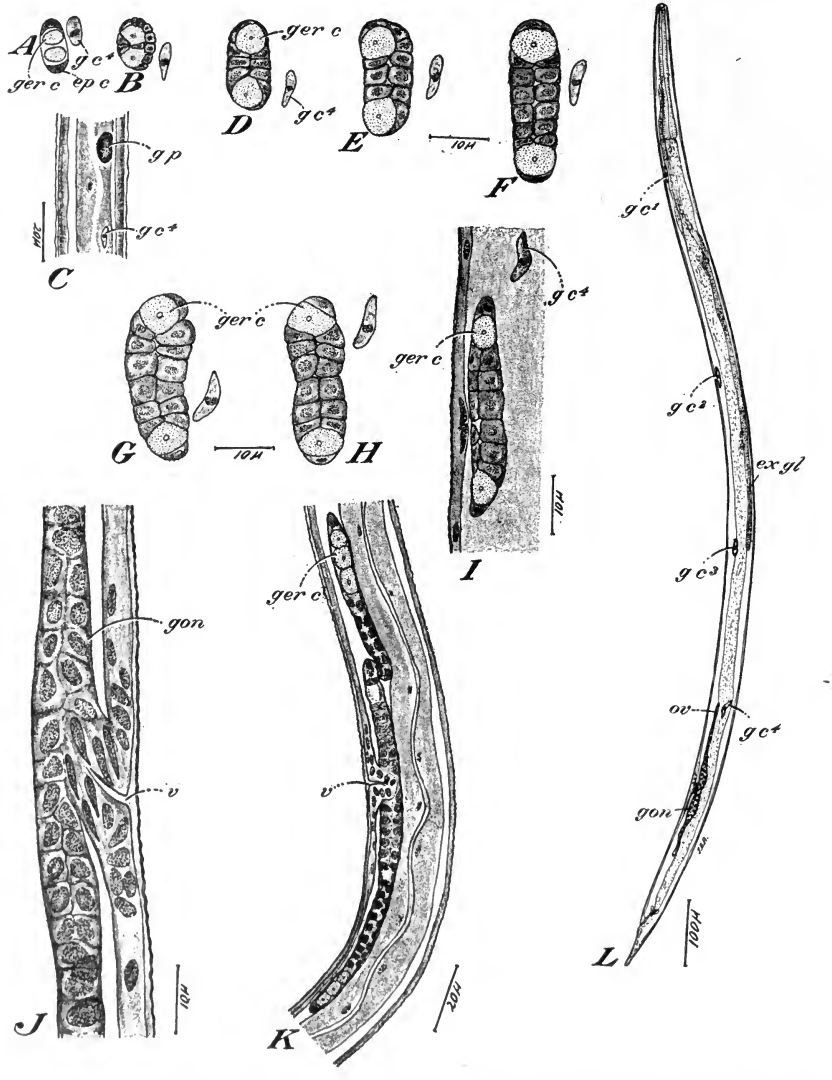

FIGURE 26.—PHASES IN THE DEVELOPMENT OF FEMALE GENITALIA AND POSITION OF GENITAL GIANT CELLS OF HYOSTRONGYLUS RUBIDUS.

A, Genital primordium of first-stage larva.

Genital primordium of third-stage larva: *B*, Of a preparasitic larva; *C*, of a preparasitic larva (position of one of the giant cells also shown); *D*, of a larva recovered from guinea pig 2 days after experimental infection; *E*, *F*, *G*, and *H*, of larvae recovered from guinea pig 4 days after experimental infection; *I*, of a larva recovered from guinea pig 5 days after experimental infection (larva on verge of third molt).

Fourth-stage larva: *J*, Region of vulva showing proliferation of cells from body wall into that of gonoduct 7 days after experimental infection; *K*, region of vulva showing differentiation of ovary and gonoduct 9 days after experimental infection; *L*, female larva 9 days after experimental infection, showing position of the four giant cells and genitalia.

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larvae taken at random showed that the number of males was slightly more than twice that of females, males constituting 68 percent and females, 32 percent. However, in a count of 150 fourth-stage larvae recovered from a guinea pig 10 days after an experimental infection, 46.6 percent were males and 53.4 percent were females.

Observations on Effects of Environment

ATTEMPTS TO INDUCE SKIN PENETRATION

This experiment was conducted in accordance with the technic described by Goodey (*35*). The skin of a 2-day-old rat was stretched, hair upward, on a cork ring, floated in a beaker containing warm physiological salt solution, and kept in an incubator at a temperature of 37° C. A small drop of water containing about 150 larvae was placed on the piece of skin and then allowed to evaporate in an incubator. One hour after the drop containing the larvae had evaporated, a drop of water was placed on the rat skin and removed to a slide by means of a pipette. Microscopic examination revealed many ensheathed larvae. No larvae were found in the salt solution. The rat skin was then fixed in 70-percent alcohol and superficial layers were mechanically separated from the deeper layers. These layers were then cleared in an alcohol-phenol mixture. Several ensheathed larvae were found on the surface of the skin, but there were no larvae in the subcutaneous layers. These findings agree with those of Goodey (*37*), who tested eight *Hyostrongylus rubidus* larvae by the cork-ring method previously described and noted that these larvae failed to penetrate the skin.

In another experiment about 200 infective larvae were placed on small areas on the skin of two young guinea pigs, the hair having been clipped from these areas. The guinea pigs were kept under restraint until the water evaporated. An hour later, a few drops of water were placed on the skin area of one guinea pig where the larvae had been placed, and after the water had remained on the skin for a short time it was transferred to a glass slide for microscopic examination. Practically all the larvae that were originally placed on the skin were recovered. The skin of the other guinea pig was thoroughly washed with water and the animal was put in a clean cage. Ten days later this animal was killed, and no larvae were recovered from the skin, lungs, or stomach.

These observations indicate that infection with these larvae does not take place through the intact skin. In their failure to penetrate the skin these larvae resemble those of other trichostrongyles, such as *Haemonchus contortus* according to Veglia (*135*) and *Obeliscoides cuniculi* according to the writer (*5*). However, some trichostrongyles, namely, *Trichostrongylus calcaratus* according to Stoll (*132*) and *Nippostrongylus muris* according to Yokogawa (*137*), have been found to be skin penetrators.

REACTION TO COLD

The ability of nematode larvae to withstand low temperatures is variable. According to Cameron (*15*), third-stage larvae of *Monodontus trigonocephalus* do not revive after being frozen for a few minutes. Ransom (*92*) noted that third-stage larvae of *Haemonchus*

contortus remained alive in sheep feces after an exposure outdoors to temperatures ranging from 21.6° to −13.8° C. for 85 days. Schwartz (*108*) reported that infective larvae of *Bustomum phlebotomum* (=*Monodontus phlebotomus*) frozen solid for about 15 hours, became active when thawed. Third-stage larvae of *Stephanurus dentatus*, according to Schwartz and Price (*113*), can withstand a temperature of −19° for 6 hours, but are killed when exposed to this temperature for 9 hours. Third-stage larvae of *Trichostrongylus* spp., according to Mönnig (*77*), were still alive after an exposure to 0° for 14 days. Ortlepp (*81*) noted that infective larvae of *Triodontophorus tenuicollis* could withstand freezing in an ice chest overnight. De Blieck and Baudet (*12*) noted that infective larvae of *Strongylus vulgaris*, *S. edentatus*, and *Cylicostomum* spp. in a culture of water and feces could withstand a temperature of 0° for 15 days. Raffensperger (*90*) exposed horse manure containing infective strongyle larvae of various species to Montana weather conditions for 20 months; some larvae did not succumb despite the fact that in the course of the experiment the temperature ranged from −18.3° to −38° for a period of 26 days in January and February 1929.

The effects of various low temperatures on the infective larvae of *Hyostrongylus rubidus* are shown in table 24. Each record is based on observations involving about 50 infective larvae. The larvae were placed in small glass tubes containing moist animal charcoal, and the tubes were placed in a refrigerator and removed from time to time for examination. The tubes remained at room temperature for about 4 hours before each examination. In case the larvae showed no motility they were kept under observation for 4 more consecutive days before being declared dead.

TABLE 24.—*Effects of low temperatures on third-stage larvae of Hyostrongylus rubidus, each culture involving about 50 larvae*

Culture no.	Period of refrigeration	Temperature of refrigerator	Condition of larvae after exposure to refrigeration	Culture no.	Period of refrigeration	Temperature of refrigerator	Condition of larvae after exposure to refrigeration
	Hours	*°C.*			*Hours*	*°C.*	
1	33	5	All active.	4	3	−20	About 20 percent active; all others dead.
2	144	3 to 5	Majority active; several showed only slight movement.	5	5	−20	About 10 percent active; all others dead.
3	720	−5 to 1	All dead.	6	9	−20	All dead.

In this experiment the *Hyostrongylus* larvae were resistant to a temperature of from 3° to 5° C. for 144 hours, but not to a temperature of from −5° to 1° for 720 hours. Temperatures during this second period of exposure lasted as follows: 1°, 24 hours; 0°, 408 hours; −1°, 24 hours; −2°, 216 hours; −5°, about 42 hours. A temperature of −20° for 9 hours destroyed the vitality of the larvae.

RESISTANCE TO DRYING

Infective larvae of strongyles vary considerably in their ability to resist desiccation. Looss (*67*) reported that infective larvae of *Strongylus* spp. and *Cylicostomum* spp. can resist desiccation in a

Petri dish for 14 days: Raffensperger (*90*) reported that 10 percent of infective lavae of *Strongylus* spp. withstood desiccation in an incubator at 26° C. for 4 months. According to Ransom (*92*), infective larvae of *Haemonchus contortus* which had been dried in feces for 35 days, revived after being moistened. Ortlepp (*81*) found that infective larvae of *Triodontophorus tenuicollis* revived after they had been dried in an incubator overnight at 26°. In contrast to these observations, Looss (*67*) pointed out that larvae of *Ancylostoma duodenale* perish as soon as their surroundings become dry. Goodey (*35*) also found that larvae of *Necator americanus* fail to revive after a few minutes of desiccation. The following experiments were conducted to determine the resistance of *Hyostrongylus* larvae to desiccation:

A small drop of water containing a number of third-stage larvae was placed on each of several glass slides. At the moment the water evaporated, the time was noted, and the slide remained exposed at room temperature for various periods, as shown in table 25. At the expiration of the various periods of time, a few drops of water were added to the dried larvae and the preparations were examined at intervals for about 24 hours. The results of these observations are given in table 25. The table shows that *Hyostrongylus* larvae are not very resistant to drying, since a 240-minute exposure proved fatal.

TABLE 25.—*Results of 5 observations on the resistance of third-stage larvae of Hyostrongylus rubidus to air drying at room temperature (24° C.)*

Larvae used in experiment (number)	Duration of exposure	Condition of larvae after the addition of water	Larvae used in experiment (number)	Duration of exposure	Condition of larvae after the addition of water
	Minutes			*Minutes*	
5	15	All active.	12	180	2 moving slowly; others dead.
5	45	2 active; 3 dead.	10	240	All dead.
5	150	1 active; 4 dead.			

LONGEVITY OF LARVAE IN WATER AT ROOM TEMPERATURE

On November 26, 1932, a number of third-stage larvae of *Hyostrongylus rubidus* were placed in a small glass receptacle containing tap water to a depth of 2 mm and also containing several large granules of washed animal charcoal. The glass receptacle was then covered with a glass slide and was placed in a large Syracuse dish which contained moistened cotton. A cover was placed on the Syracuse dish and sealed with petrolatum. The experiment was conducted at room temperature (22° to 24° C.). Larvae in this condition were found to be somewhat active on February 10, 1933. When examined on March 15, the larvae were dead and somewhat disintegrated. Apparently third-stage larvae will survive in water, with some charcoal added, for a period of 2½ months but not for 3½ months, at room temperature.

STRONGYLIDAE

OESOPHAGOSTOMUM DENTATUM (RUDOLPHI, 1803) MOLIN, 1861

(Fig. 27)

Synonyms.—*Strongylus dentatus* Rudolphi, 1803; *Sclerostoma dentatum* (Rudolphi, 1803) Rudolphi, 1809; *Oesophagostomum subulatum* Molin, 1861; *Strongylus follicularis* (?) Ostertag, in Olt, 1898.

Hosts.—Swine and wild boar.

Location.—Adults in large intestine.

Distribution.—Africa (Zanzibar), Asia (China, Philippines, India), Europe, North America (British West Indies, Puerto Rico, United States), South America, and Oceania (Tonga Island).

Description of Egg and Preparasitic Larval Stages

EGG

Eggshell thin, transparent, and usually elliptical (fig. 27, *A*). In a series of measurements involving about 50 eggs, length 61μ to 83.5μ, width 38μ to 53μ. Eggs in an early cleavage stage, containing from about 8 to 16 cells, when passed in feces.

EMBRYO

Embryo, when ready to hatch, resembling first-stage larva.

FIRST-STAGE LARVA

Shape and size.—In shape (fig. 27, *C* and *E*) first-stage larva similar to corresponding stage of *Hyostrongylus rubidus*. Larvae, soon after hatching, 304μ to 311μ long by 15μ wide, and before first molt 425μ to 433μ long by 19μ wide (table 26).

Cuticle.—Thin with very fine transverse striations.

Alimentary tract.—In general, same as in first-stage larva of *Hyostrongylus rubidus*. Buccal cavity 11μ to 15μ long; esophagus rhabditiform, 83μ to 97μ long; intestine slightly granular, with a sinous lumen.

Nervous system.—Nerve ring appearing as a band encircling esophagus 76μ to 85μ from anterior end.

Excretory system.—Excretory pore inconspicuous in young larva of this stage, about 90μ from anterior end.

Genital primordium.—Small elliptical body, 155μ to 225μ from anterior end.

Table 26 shows the rate of development of first-stage larvae of *Oesophagostomum dentatum* in moist charcoal-feces media at room temperature (22° to 24° C.), the measurements having been made at different periods after preparation of the culture.

TABLE 26.—*Principal measurements of 7 first-stage larvae of Oesophagostomum dentatum at various periods of development*

Item	Period of development and measurements of larva no.—						
	1	2	3	4	5	6	7
Period of development ..... hours	1	1	18	18	18	[1] 27	[1] 27
Length of body ..... microns	304	311	400	410	421	425	433
Maximum width of body ..... do	15	15	19	19	19	19	19
Length of buccal cavity ..... do	11	11	15	15	15	15	15
Length of esophagus ..... do	83	83	95	97	97	97	------
Distance of nerve ring from anterior end ..... do	76	------	83	85	85	80	80
Distance of excretory pore from anterior end ..... do	------	------	90	90	90	90	------
Distance of genital primordium from anterior end ..... do	155	162	212	218	220	215	225
Length of tail ..... do	83	83	114	114	117	117	117

[1] Larva undergoing first molt.

SECOND-STAGE LARVA

Shape and size.—In shape (fig. 27, *D*) similar to second-stage larva of *Hyostrongylus rubidus*. Larvae 440μ to 655μ long by 21μ to 32μ wide (table 27).

Cuticle.—With very fine transverse striations.

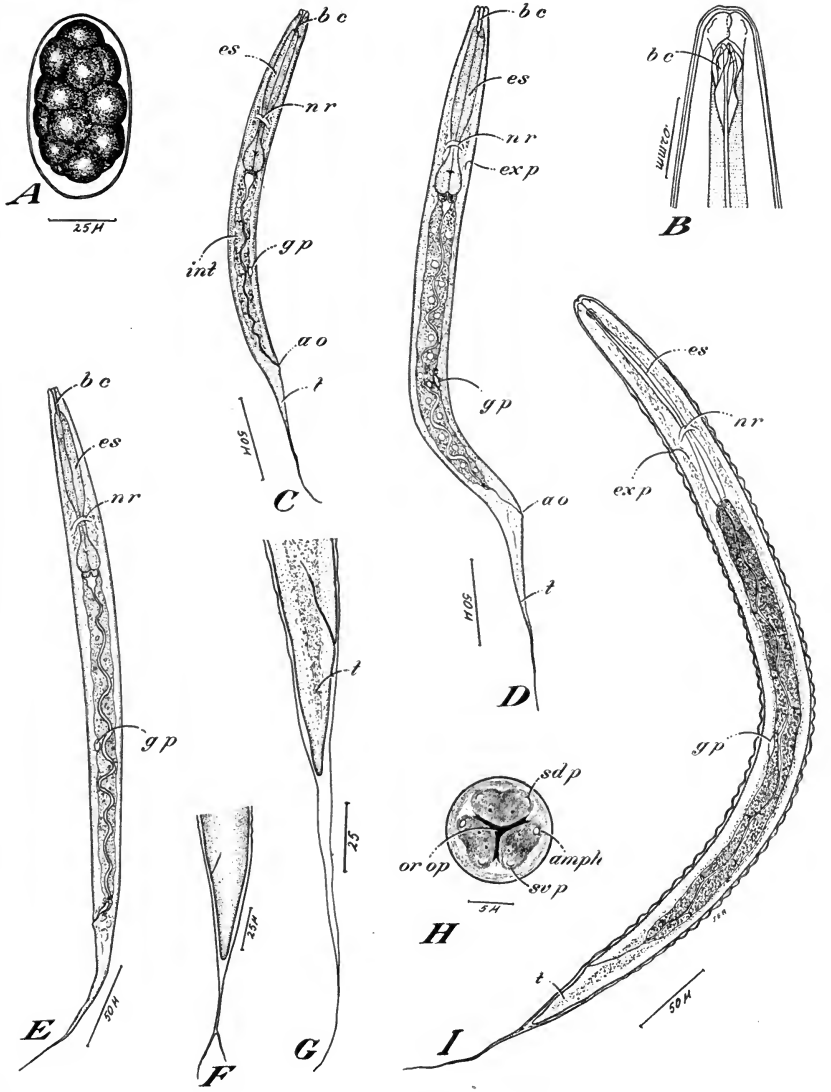

FIGURE 27.—VARIOUS STAGES IN THE DEVELOPMENT OF OESOPHAGOSTOMUM DENTATUM.

A, Egg.

First-stage larva: *C*, Newly hatched, lateral view; *E*, lateral view of fully grown larva.

D, Second-stage larva, lateral view.

Third-stage larva: *B*, Anterior end, showing features of buccal cavity (from Goodey (1924) slightly modified); *H*, anterior end of larva, en face view; *F*, malformation of tip of tail in shed cuticle; *G*, posterior portion of larva; *I*, lateral view of larva.

Alimentary tract.—In general, as in second-stage larva of *Hyostrongylus rubidus*. Buccal cavity 15μ long; esophagus rhabditiform, 102μ to 130μ long; intestine slightly granular and similar to that in first-stage larva.

Nervous system.—Nerve ring 85μ to 95μ from anterior end.

Excretory system.—Excretory pore 95μ to 121μ from anterior end.
Genital primordium.—As in first-stage larva; 225μ to 330μ from anterior end.

Table 27 shows the rate of development of second-stage larvae of *Oesophagostomum dentatum* in moist charcoal-feces media at room temperature (22° to 24° C.), the measurements having been made at different periods after preparation of the culture.

TABLE 27.—*Principal measurements of 7 second-stage larvae of Oesophagostomum dentatum at various periods of development*

Item	Period of development and measurements of larva no.—						
	1	2	3	4	5	6	7
Period of development.....hours	42	42	66	66	66	[1] 100	[1] 100
Length of body.....microns	440	497	509	521	624	639	655
Maximum width of body.....do	21	24	24	26	30	30	32
Length of buccal cavity.....do	15	15	15	15	15	15	15
Length of esophagus.....do	102	110	115	112	121	121	130
Distance of nerve ring from anterior end.....do	85	90	90	90	95	95	95
Distance of excretory pore from anterior end.....do	95	102	110	105	114	117	121
Distance of genital primordium from anterior end.....do	225	255	260	265	310	322	330
Length of tail.....do	125	122	125	125	132	152	152

[1] Larva undergoing second molt.

THIRD-STAGE LARVA

Shape and size.—In general, body similar in shape to that of previous stage (fig. 27, *I*). In en face view, head with 3 inconspicuous lips, 1 dorsal and 2 subventral; dorsal lip with 2 subdorsal papillae; each subventral lip with 1 subventral papilla and 1 lateral amphid; an inner circle of 2 minute papillae apparently present on each of the lips (fig. 27, *H*). Tail of larva somewhat conical, ending in a characteristic, somewhat pointed tip (fig. 27, *G*). Characteristic sheath surrounding third-stage larva, showing many evenly arranged folds throughout most of its length (fig. 27, *I*). Larva, excluding sheath, 500μ to 532μ long by 26μ wide; according to Goodey (*36*), larva (including sheath) 660μ to 720μ long by 30μ wide.

Cuticle.—With fine transverse striations.

Alimentary tract.—Oral opening leading into short narrow lumen connecting posteriorly with modified portion of buccal cavity; cuticular lining surrounding buccal cavity, as observed by Goodey (*36*); lining apparently drawn out into thin strands of fibers, the fibers spreading out and interlacing, forming a complex network (fig. 27, *B*). Esophagus strongyliform, 144μ to 152μ long. Intestine composed of 8 dorsal and 8 ventral cells, connecting posteriorly with a slender rectal canal.

Nervous system.—In general, corresponding to that of *Hyostrongylus rubidus;* nerve ring 91μ to 95μ from anterior end.

Excretory system.—Excretory pore 98μ to 110μ from anterior end; pore connecting with a canal leading backward and becoming indistinguishable in passing between cells of nervous system.

Genital primordium.—Location as in previous stages; 273μ to 318μ from anterior end.

Table 28 shows the measurements of third-stage larvae of *Oesophagostomum dentatum.*

TABLE 28.—*Principal measurements of 6 third-stage larvae of Oesophagostomum dentatum* [1]

Item	Period of development and measurements of larva no.—					
	1	2	3	4	5	6
Period of development.....days	6	6	6	6	6	6
Length of body.....microns	500	509	516	520	530	532
Maximum width of body.....do	26	26	26	26	26	26
Length of esophagus.....do	144	148	144	152	152	152
Distance of nerve ring from anterior end.....do	91	91	95	95	91	95
Distance of excretory pore from anterior end.....do	98	102	102	102	106	110
Distance of genital primordium from anterior end.....microns	273	300	296	296	311	318
Length of tail.....do	45	45	49	49	51	53

[1] Measurements do not include sheath.

DIFFERENCES IN FIRST THREE STAGES

The outstanding differential features of the first three larval stages of *Oesophagostomum dentatum* are as follows:

First-stage larva.—Buccal cavity long, with parallel rod-shaped walls, opening directly to the outside; esophagus rhabditiform; tail long and pointed; larvae 304μ to 433μ long by 15μ to 19μ wide.

Second-stage larva.—Buccal cavity, esophagus, and tail as in first-stage larva; larvae 440μ to 655μ long by 21μ to 32μ wide.

Third-stage larva.—Buccal cavity short, with cuticular walls drawn out into thin strands of fibers spreading out and interlacing into a complex network; buccal cavity opening to outside by narrow lumen; esophagus strongyliform; tail short, conical, terminating in a rounded tip. Larvae 500μ to 532μ long by 26μ wide, and surrounded by sheath of second molt, sheath possessing numerous evenly arranged folds throughout most of its length.

Development of Preparasitic Larval Stages

Little information is available in the literature as to the time required for the development of the various preparasitic stages of *Oesophagostomum dentatum*. Goodey (*36*) noted that from 18 to 20 hours after being passed with the feces of pigs, eggs of this parasite contained an embryo which was apparently approaching the tadpole stage.

The writer has cultured eggs of *O. dentatum* in a moist charcoal-feces medium as described for *Hyostrongylus rubidus*. The results obtained at room temperature (22° to 24° C.) are shown in the following tabulation. It is noted that the movements of third-stage larvae are somewhat slow in contrast to those of *H. rubidus*.

Hours after incubation	*Degree of development*
0	1-cell to about 16-cell stage.
18	Majority of eggs containing fully developed embryos.
23	Eggs hatching.
41	Majority of larvae in first stage.
50	First lethargus in progress.
65	Few larvae in second stage.
89	Majority of larvae in second stage.
123	Second lethargus in progress.
137	Few larvae in second molt (=third stage).

Observations on Effects of Environment

ATTEMPTS TO INDUCE SKIN PENETRATION

The writer has confirmed the findings of Goodey (*36*) that third-stage larvae of *Oesophagostomum dentatum* fail to penetrate the skin of young rats when the skin is stretched on a cork ring and floated on a warm physiologic saline solution.

REACTION TO COLD

There is no information in the available literature with reference to the reaction of third-stage larvae to cold. The writer made such a study, and the results of the observations are given in table 29. Each record is based on observations involving about 300 third-stage larvae. These larvae were placed in small glass tubes containing moist animal charcoal; larvae were removed from the culture from time to time for examination. Before the larvae were examined microscopically, the tubes were kept at room temperature for 6 hours, and the larvae were examined on the same day and for the next 4 consecutive days. The data in table 29 show that some third-stage

larvae of *O. dentatum* were somewhat resistant to low temperature. Some of the larvae still showed signs of life when exposed to −19° to −29° C. for 10 days, but their vitality was destroyed when kept at temperatures of −15° to −29° for 31 days.

TABLE 29.—*Effects of low temperatures on the infective larvae of Oesophagostomum dentatum, each culture involving about 300 larvae*

Culture no.	Period of refrigeration		Temperature of refrigerator	Condition of larvae after exposure to refrigeration
	Days	*Hours*	° *C.*	
1	1	9	5	All active.
2	6		3 to 5	Majority active; few slightly active.
3		9	−20	15 moved slowly, others responded to heat only.
4	2		−20 to −21	About 10 moved slowly and about 50 percent responded to heat; others dead.
5	5		−17 to −21	About 10 moved slowly, and about 25 percent responded to heat; others dead.
6	10		−17 to −20	About 8 responded to heat; others dead.
7	10		−19 to −29	2 responded to heat; others dead.
8	31		−15 to −29	All dead.

REACTION TO DESICCATION

Goodey (*36*) reports that third-stage larvae of *O. dentatum*, when dried in glass capsules for 1 or 2 days, revived on the addition of water. The writer, however, could not confirm Goodey's observation. Larvae in a small drop of water were placed on each of several glass slides, and the water was allowed to evaporate. At the moment the water evaporated the time was noted, and the glass slide then remained exposed at room temperature for various periods, as shown in table 30. At the expiration of the desired lapse of time, a few drops of water were added to the dried larvae, and the preparation was examined microscopically at various intervals during about 24 hours. The results of the observations are given in the table which shows that some larvae died after being desiccated for 30 minutes, but that one larva showed signs of life even after 20 hours of drying. All the larvae were dead after 22 hours of drying.

TABLE 30.—*Results of observations on the resistance of third-stage larvae of Oesophagostomum dentatum to air drying at room temperature (22° to 24° C.)*

Larvae used (number)	Duration of exposure		Condition of larvae after the addition of water	Larvae used (number)	Duration of exposure		Condition of larvae after the addition of water
	Hours	*Minutes*			*Hours*	*Minutes*	
15		10	All active.	22	18		1 moved anterior end in response to heat; all others dead.
17		30	2 dead; all others active.				
19	1		5 dead; all others moved or responded to heat.	50	20		Do.
16	2		1 active; 3 responded to heat; all others dead.	30	22		All dead.
22	5		3 moved slowly; all others dead.				

LONGEVITY OF LARVAE IN WATER AT ROOM TEMPERATURE

On November 26, 1932, third-stage larvae of *Oesophagostomum dentatum* were placed in a small glass receptacle containing water and animal charcoal, as described for *Hyostrongylus rubidus*, kept at room temperature (22° to 24° C.), and examined at least once every month. The last examination was made on September 15, 1933, at which time the larvae were still active and appeared normal.

STEPHANURUS DENTATUS DIESING, 1839

(Fig. 28)

Synonyms.—*Sclerostoma dentatum* (Diesing, 1839) Leidy, 1856, not Rudolphi, 1803; *S. pinguicola* Verrill, 1870; *Strongylus dentatus* (Diesing, 1839) Dean, 1874, not Rudolphi, 1803; *Stephanurus nattereri* Cobbold, 1879; *Strongylus pinguicola* (Verrill, 1870) Malgalhães, 1894; *Sclerostomum renium* Drabble, 1922; *Stephanurus morai* Almeida, 1928.

Hosts.—Swine, cattle, and, experimentally, guinea pig.

Location.—Adults in kidney fat, kidneys, ureters, urinary bladder, lungs, pleural cavity, lumbar muscles, spleen, and spinal canal.

Distribution.—Africa (Belgian Congo, Dahomey, French Congo), Asia (Indo-China, Java, Philippines, Sumatra), Australia, Europe (Spain), Central America (Nicaragua, Panama), North America (British West Indies, Cuba, Mexico, United States), South America (Argentina, Brazil, Uruguay), and Oceania (Cook Islands, Guam).

DESCRIPTION OF EGG AND PREPARASITIC LARVAL STAGES

EGG

Egg with thin, transparent, oval shell; poles usually unequal, one usually more convex than other (fig. 28, *A*); abnormalities in shape of shell occasionally present, one or both extremities being somewhat flat instead of rounded. In a series of measurements involving 50 eggs, length 91μ to 114μ, width 53μ to 65μ; segmenting eggs 208μ long by 72μ wide have been found, but such extreme size possibly represents an abnormality; according to Bernard and Bauche (*11*) eggs 100μ to 120μ long by 55μ wide, according to Ross and Kauzal (*101*) most typical eggs 104μ to 136μ long by 56μ to 64μ wide. When deposited in urine of host, egg advanced in cleavage and composed of from 32 to 64 cells.

EMBRYO

Embryo, just before hatching, resembling first-stage larva.

FIRST-STAGE LARVA

Shape and size.—In shape (fig. 28, *E*) first-stage larva similar to corresponding stage of *Hyostrongylus rubidus;* anterior end somewhat rounded in lateral view; head papillae not very distinct. Three hours after hatching, larvae 410μ to 421μ long by 24μ wide, attaining a length of about 530μ and a width of 26μ before molting (table 31).

Cuticle.—Thin and apparently without transverse striations.

Alimentary tract.—In general, as in first-stage larva of *Hyostrongylus rubidus.* Buccal cavity 11μ to 15μ long; esophagus rhabditiform, 95μ to 114μ long. Intestine more granular than that of any other first-stage larva of a swine nematode; walls of intestinal cells inconspicuous; lumen of intestine sinous in outline.

Nervous system.—Nerve ring appearing as a band encircling esophagus, 66μ to 91μ from anterior end.

Excretory system.—Excretory pore inconspicuous in young larva of this stage, 85μ to 98μ from anterior end.

Genital primordium.—Represented by a small elliptical body ventral in position, 215μ to 273μ from anterior end.

Table 31 shows the rate of development of first-stage larvae of *Stephanurus dentatus* in moist charcoal-feces media at room temperature (22° to 24° C.), the measurements having been made at different periods after the preparation of the culture.

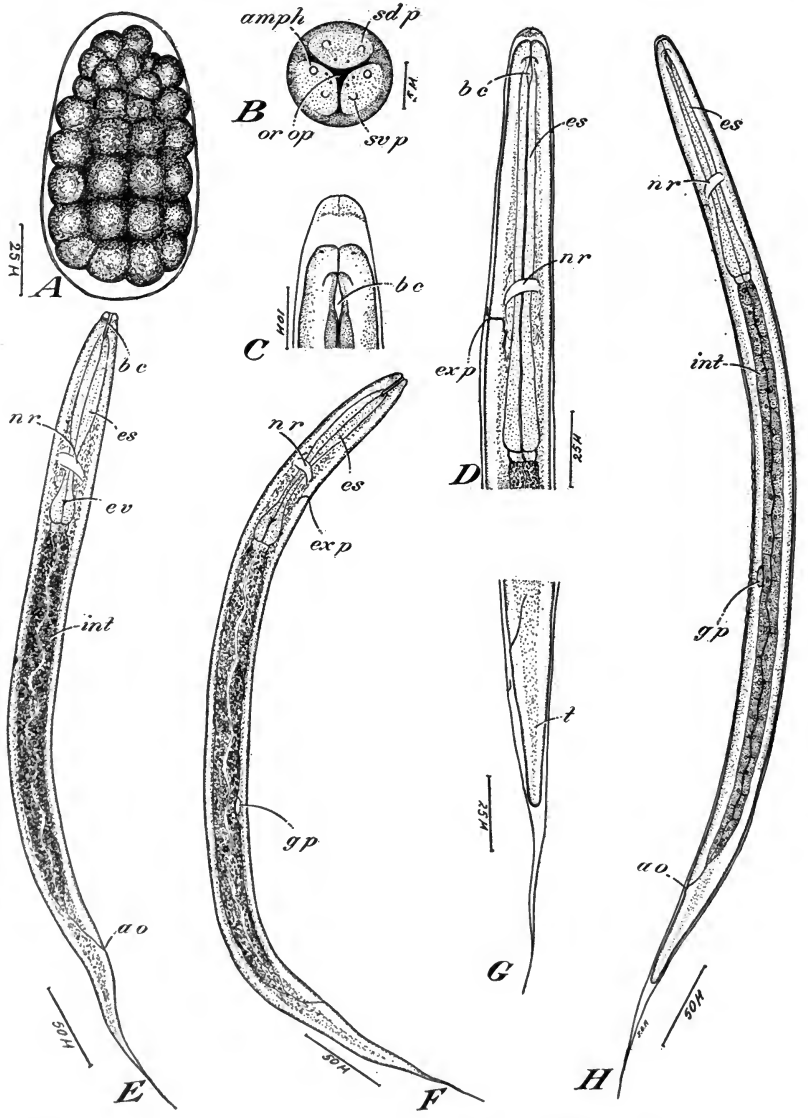

FIGURE 28.—VARIOUS STAGES IN THE DEVELOPMENT OF STEPHANURUS DENTATUS.
A, Egg.
E, First-stage larva, lateral view.
F, Second-stage larva, lateral view.
Third-stage larva: *B*, Anterior end, en face view; *C*, anterior end, showing shape of buccal cavity; *D*, anterior portion, lateral view; *G*, posterior portion, lateral view; *H*, lateral view of larva.

TABLE 31.—*Principal measurements of 5 first-stage larvae of Stephanurus dentatus at various periods of development*

Item	Period of development and measurements of larva no.—				
	1	2	3	4	5
Period of development.....hours..	3	3	8	8	[1] 20
Length of body.....microns..	410	421	452	468	530
Maximum width of body.....do....	24	24	24	24	26
Length of buccal cavity.....do....	11	11	11	15	15
Length of esophagus.....do....	95	108	110	108	114
Distance of nerve ring from anterior end.....do....	66	70	78	78	91
Distance of excretory pore from anterior end.....do....	------	------	------	85	98
Distance of genital primordium from anterior end.....do....	215	220	230	240	273
Length of tail.....do....	95	102	102	106	106

[1] Larva undergoing first molt.

SECOND-STAGE LARVA

Shape and size.—In shape (fig. 28, *F*) similar to second-stage larva of *Hyostrongylus rubidus*. Papillae of anterior end not very distinct. Larvae 530μ to 580μ long by 26μ to 28μ wide (table 32); according to Ross and Kauzal (*101*), 540μ long by 27μ to 32μ wide.

Cuticle.—Transverse striations not visible at this stage.

Alimentary tract.—In general as in second-stage larvae of *Hyostrongylus rubidus*. Buccal cavity 15μ long; esophagus rhabditiform, 110μ to 136μ long; intestine somewhat granular.

Nervous system.—Nerve ring 83μ to 91μ from anterior end.

Excretory system.—Excretory pore inconspicuous, 91μ to 102μ from anterior end.

Genital primordium.—As in first-stage larva; 250μ to 304μ from anterior end.

Table 32 shows the rate of development of second-stage larvae of *Stephanurus dentatus* in moist charcoal-feces media at room temperature (22° to 24° C.), the measurements having been made at different periods after preparation of the culture.

TABLE 32.—*Principal measurements of 5 second-stage larvae of Stephanurus dentatus at various periods of development*

Item	Period of development and measurements of larva no.—				
	1	2	3	4	5
Period of development.....hours..	41	41	41	65	[1] 70
Length of body.....microns..	530	535	535	540	580
Maximum width of body.....do....	26	26	26	26	28
Length of buccal cavity.....do....	15	15	15	15	15
Length of esophagus.....do....	110	114	125	114	136
Distance of nerve ring from anterior end.....do....	91	83	91	91	91
Distance of excretory pore from anterior end.....do....	------	91	98	98	102
Distance of genital primordium from anterior end.....do....	250	256	256	281	304
Length of tail.....do....	102	106	117	122	117

[1] Larva undergoing second molt.

THIRD-STAGE LARVA

Shape and size.—In general, body similar in shape to that of previous stage, but more slender (fig. 28, *H*). In en face view, head with 3 inconspicuous lips, 1 dorsal and 2 subventral; dorsal lip with 2 subdorsal papillae; each subventral lip with 1 subventral papilla and 1 lateral amphid; an inner circle of 2 minute

papillae apparently present on each of the lips (fig. 28, *B*). Number of lips as noted by the writer is at variance with that reported by Ross and Kauzal (*101*) who found 4 inconspicuous lips, 2 dorsal and 2 subventral. Tail of larva somewhat conical, ending in a characteristic rounded tip (fig. 28, *G*). Owing to reduced length of tail, larvae 518μ to 610μ long by 24μ to 26μ wide; according to Ross and Kauzal (*101*), 607μ long by 28μ wide.

Cuticle.—With fine transverse striations.

Alimentary tract.—Oral opening leading into short narrow lumen connecting posteriorly with characteristic spindle-shaped buccal cavity (fig. 28, *C*); in optical section cuticular lining of cavity apparently sending out a pair of short, laterally directed fibers at anterior portion of cavity. Esophagus strongyliform, its base characteristically broader than that of corresponding stage of other larvae of swine strongyles. Intestine less granular than in previous larval stages and with 16 dorsal and 16 ventral cells; intestine connecting posteriorly with a slender rectal canal.

Nervous system.—In general, corresponding to that of *Hyostrongylus rubidus;* nerve ring 85μ to 92μ from anterior end.

Excretory system.—Excretory pore 91μ to 105μ from anterior end; pore connecting with a canal extending backward and becoming indistinguishable in passing between cells of nervous system.

Genital primordium.—Location as in previous stages; 288μ to 342μ from anterior end.

Table 33 gives the measurements of third-stage larvae of *Stephanurus dentatus.*

TABLE 33.—*Principal measurements of 5 third-stage larvae of Stephanurus dentatus* [1]

Item	Period of development and measurements of larva no.—				
	1	2	3	4	5
Period of development—days	7	7	7	7	7
Length of body—microns	518	518	520	537	610
Maximum width of body—do	24	24	24	24	26
Length of esophagus—do	125	128	132	134	136
Distance of nerve ring from anterior end—do	85	87	85	85	92
Distance of excretory pore from anterior end—do	96	102	91	91	105
Distance of genital primordium from anterior end—do	288	290	290	294	342
Length of tail—do	49	53	50	49	57

[1] Measurements do not include sheath.

DIFFERENCES IN FIRST THREE STAGES

The outstanding differential features of the first three larval stages of *Stephanurus dentatus* are as follows:

First-stage larva.—Buccal cavity long with parallel rod-shaped walls, opening directly to exterior; esophagus rhabditiform; intestine very dark and granular; tail long and pointed; larvae about 410μ to 530μ long by 24μ to 26μ wide.

Second-stage larva.—Buccal cavity, esophagus, intestine, and tail as in first stage; larvae about 530μ to 580μ long by 26μ to 28μ wide.

Third-stage larva.—Buccal cavity short, spindle-shaped, opening anteriorly by a narrow lumen; esophagus strongyliform; intestine less dark and granular than in previous stages; tail short, conical, terminating in a rounded tip; larvae 518μ to 610μ long by 24μ to 26μ wide.

DEVELOPMENT OF PREPARASITIC LARVAL STAGES

Considerable information is already available concerning the development of the preparasitic stages of *Stephanurus dentatus.* Bernard and Bauche (*11*) noted that eggs cultured in animal charcoal and urine hatched in 24 hours and that the third stage was reached 5 days later. Schwartz and Price (*113*) reported that at a tempera-

ture of about 26° to 27° C., *Stephanurus* eggs hatched in 24 to 48 hours, and third-stage larvae were present in 5 to 6 days after the culture was prepared. They found that low temperatures retarded the development of the eggs and the larvae; thus, at a temperature of about 10°, the eggs not only failed to develop, but their vitality was destroyed in 10 days. Ross and Kauzal (*101*) noted that when eggs were cultured at 25° to 27.5° in a medium containing water with a few drops of filtered decoction of pig feces, the larvae hatched in 24 to 36 hours; the first molt occurred 16 to 30 hours after hatching and the second molt 36 to 48 hours after the commencement of the second stage; the third stage was usually reached 95 to 120 hours after culturing of the eggs, but in exceptional cases, at 30° the third stage was reached in 85 hours.

The writer cultured eggs of *S. dentatus* in a moist charcoal-feces medium, as described for *Hyostrongylus rubidus*. The results at room temperatures (22° to 24° C.) are given in the following tabulation. It was noted that the movement of third-stage larvae in moist charcoal medium was more active than that of the sluggish third-stage *Oesophagostomum* larvae, but slightly less active than that of third-stage larvae of *Hyostrongylus rubidus*.

Hours after incubation	*Degree of development*
0	1-cell to advanced morula stage.
23	Eggs hatching.
40	Majority of larvae in first stage.
43	First lethargus in progress.
64	Few larvae in second stage.
88	Majority of larvae in second stage.
93	Second lethargus in progress.
112	Few larvae in second molt (=third stage).

Observations on Effects of Environment

Attempts to induce skin penetration

Information concerning the ability of third-stage larvae of *Stephanurus* to penetrate the skin of the final host has aroused considerable discussion among some parasitologists. Bernard and Bauche (*11*) stated that they infected pigs experimentally with *Stephanurus dentatus* as a result of skin penetration by third-stage larvae. Schwartz and Price (*112, 113, 114*) on the other hand, in an extensive investigation regarding skin penetration, concluded that when *Stephanurus* larvae are placed on the intact skin of pigs they are incapable of penetrating it; these writers showed, however, that if the skin of the pig were scarified, the larvae would penetrate and develop in their usual location. Ross and Kauzal (*101*), however, stated that they produced an experimental infection of kidney worms in pigs by placing larvae in feces and mud on the intact skin of live pigs or guinea pigs. Lately, Spindler (*125*) cleared up the difference of opinion with reference to skin penetration of *Stephanurus* larvae. He confirmed the findings of Schwartz and Price to the effect that third-stage larvae in water when placed on the intact skin of pigs are unable to infect these animals, and confirmed the findings of Ross and Kauzal to the effect that infection occurs readily when charcoal and feces or soil and feces cultures containing third-stage larvae are spread on the intact skin of pigs. Spindler expressed the opinion that traction

probably plays a part in aiding the larvae to penetrate the intact skin.

In two cases the writer, using Goodey's (*35*) cork-ring skin-penetration method, failed in attempts to bring about the penetration of *Stephanurus* larvae through the skin of 2-day-old rats, results which are in harmony with the findings of Schwartz and Price (*113*) and Ross and Kauzal (*101*).

REACTION TO COLD

Infective *Stephanurus* larvae are not very resistant to low temperature. Schwartz and Price (*113*) showed that at a temperature of −19° C. the vitality of the larvae was destroyed in 9 hours, but that 6 hours' exposure to this temperature was not fatal. Experiments conducted by the writer on the resistance of larvae to a temperature of −19° confirmed the finding of Schwartz and Price (*113*).

RESISTANCE TO DESICCATION

Infective larvae of *Stephanurus dentatus* are not very resistant to desiccation. Schwartz and Price (*113*) noted that when larvae were air-dried at room temperature on a slide, their vitality was destroyed in about 30 minutes, but shorter periods of exposure did not prove fatal to all larvae. Ross and Kauzal (*101*) ascertained that some larvae exposed in bright sunshine (43.3° C.) resisted 5 to 10 minutes of desiccation, but all were found dead in 15 minutes. Practically the same results were obtained by De Jesus[4] who found that *Stephanurus* larvae in dust exposed to bright sunlight for 5 or 10 minutes remained alive, whereas an exposure of 15 or more minutes proved fatal.

The writer has dried larvae on glass slides at room temperature and has noted that only a few larvae survived an exposure of 30 minutes. Drying for 20 minutes proved fatal to some larvae, but all of them succumbed to an exposure of 1 hour or longer (table 34). These findings are in agreement with those of Ross and Kauzal (*101*) who found that a few larvae survived an exposure of 30 minutes, but that an exposure of 1 hour was fatal.

TABLE 34.—*Results of observations on the resistance of third-stage larvae of Stephanurus dentatus to air drying at room temperature (24° C.)*

Larvae used (number)	Length of exposure	Condition of larvae after addition of water	Larvae used (number)	Length of exposure	Condition of larvae after addition of water
	Minutes			*Minutes*	
25	5	All active.	30	30	4 active; 26 dead.
20	10	Do.	28	60	All dead.
20	15	Do.	25	180	Do.
25	20	12 active; 13 dead.			

LONGEVITY OF INFECTIVE LARVAE

According to Ross and Kauzal (*101*), the longevity of infective larvae varies considerably in the different media used. In soil and feces media they recovered most of the larvae alive up to the one hundred and eighth day. Beyond this period the number of live

[4] JESUS, Z. DE. THE RESISTANCE OF THE EGGS AND LARVAE OF SWINE KIDNEY WORM, STEPHANURUS DENTATUS DIESING, WITH SPECIAL REFERENCE TO THE CONTROL OF STEPHANURIASIS. Philippine Islands Bur. Anim. Indus. Gaz. 3(2): 98–108. 1933. [Mimeographed.]

larvae which they recovered diminished progressively; on the one hundred and fifty-fourth day only a few larvae were alive. These authors also noted that in liquid medium few larvae survived more than 50 days, and in agar all larvae degenerated in 28 days. De Jesus [5] reported that when third-stage larvae were placed in a layer of dust about 3 mm deep, about half of them died after 47 days, and by the fifty-fifth day all the larvae were disintegrated.

The writer has kept infective larvae of *Stephanurus* in a moist charcoal-and-feces mixture for 40 days at room temperature, and after that period several active larvae were recovered with the aid of the Baermann apparatus.

STRONGYLOIDIDAE

STRONGYLOIDES RANSOMI SCHWARTZ AND ALICATA, 1930

(Figs. 29–30)

Host.—Swine.
Location.—Adults in small intestine.
Distribution.—North America (United States).

Larval Stages and Development

Eggs of *Strongyloides ransomi* derived from parasitic female worms give rise to embryos which after hatching pursue one of two cycles of development, direct or indirect. In the direct cycle, the larvae grow and after two molts, according to Lucker (*69*), transform into third-stage (strongyliform) larvae capable of infecting the host. In the indirect cycle the larvae grow and after four molts, according to Lucker, develop into adult free-living males and females; the females give rise to embryonated eggs which hatch, the larval worms molting twice and developing to third-stage strongyliform larvae capable of infecting a suitable host.

The number of molts observed by Lucker in *Strongyloides ransomi* is at variance with the number reported for other species of *Strongyloides*. Various writers, namely, Grassi and Parona (*39*), Perroncito (*88*), Leuckart (*61*), Grassi and Segré (*40*), Golgi and Monti (*33*), Zinn (*143*), Leichtenstern (*57*), Gonder (*34*), and Kreis (*55*), mention only one molt in the direct cycle of development of *Strongyloides stercoralis* and other species of *Strongyloides*.

Bavay (cited by Schuurmans Stekhoven (*107*)) and Oudendal (*84*) state that young first-stage larvae of *S. stercoralis* molt in the intestine of the host before passing out with the feces. Unfortunately there is no clue as to whether larvae seen molting in the intestine are of the direct or indirect cycle of development; however, such a molt may explain why many investigators have noted only one molt in larvae which followed the direct cycle of development, the explanation being that one molt had already occurred during the passage of the larvae through the intestine to the outside world.

According to Looss (*67*), larvae of *S. stercoralis* pursuing the indirect cycle molted only once before reaching sexual maturity. On the other hand, Lucker reports four molts in the corresponding cycle of *S. ransomi*. The progeny of the free-living forms of *S. stercoralis* and *S. ransomi*, according to Looss (*66*, *67*) and Lucker, respectively, molt twice before reaching the strongyliform stage (=third stage). The writer also has noted two molts in the course of development of eggs from free-living females to strongyliform larvae.

[5] See footnote on p. 78.

Description of Egg, Embryo, and Larval Stages Undergoing Direct Development

EGG (FROM PARASITIC FEMALE)

Eggshell thin, transparent, and usually elliptical (fig. 29, *A*). In a series of measurements of 50 eggs, length 53μ to 57μ, width 30μ to 34μ; usually in late tadpole stage when passed with feces of host.

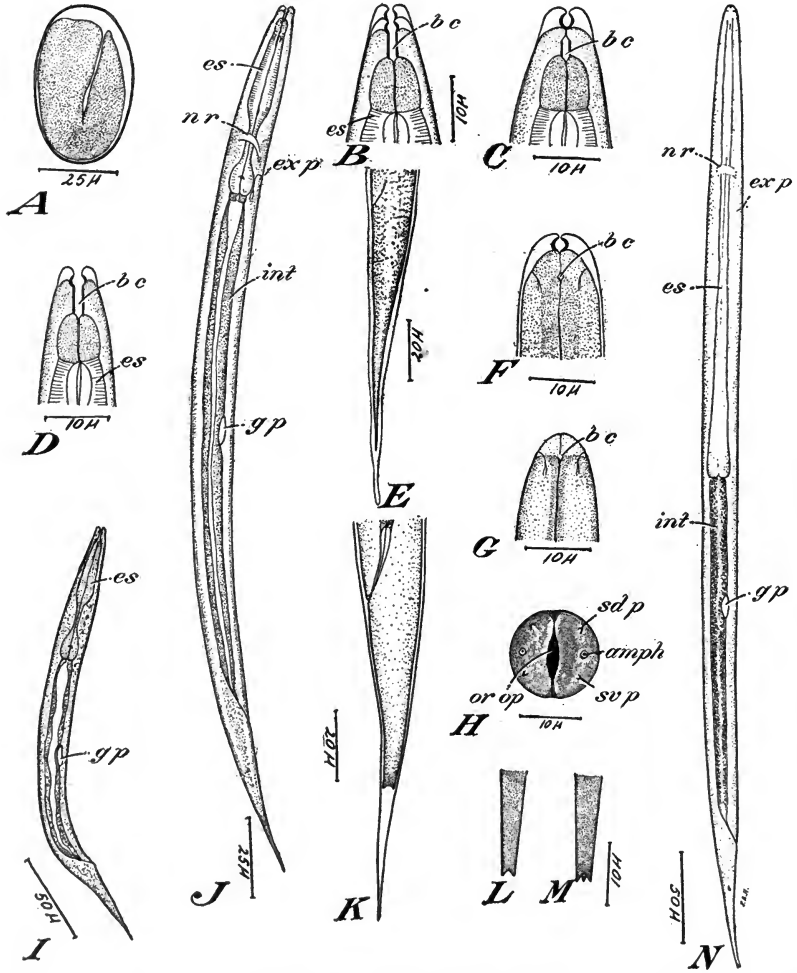

FIGURE 29.—VARIOUS STAGES IN THE DEVELOPMENT OF STRONGYLOIDES RANSOMI.

A, Egg, as recovered from freshly deposited feces.

First-stage larva: *D*, Anterior portion; *I*, newly hatched larva; *J*, larva of direct cycle of development; *B*, anterior end of larva of indirect cycle (?) of development undergoing first molt; *E*, posterior end of larva of indirect cycle (?) of development undergoing first molt.

Second-stage larva (direct cycle): *C* and *F*, Anterior end of larvae undergoing second molt; *K*, posterior end of larva undergoing second molt.

Third-stage (strongyliform) larva: *G*, Anterior end, lateral view; *H*, anterior end, en face view; *L*, showing processes at tip of tail, lateral view; *M*, showing processes at tip of tail, ventral view; *N*, lateral view of larva.

EMBRYO

Just before oviposition, embryo fairly well developed, resembling first-stage larva; just before hatching embryos 228μ to 235μ long by 15μ wide; morphology of fully developed embryo as in first-stage larva.

FIRST-STAGE LARVA

Shape and size.—Body cylindrical for most of its length, tapering slightly anteriorly and more so posteriorly (fig. 29, *I* and *J*); anterior end with 6 minute elevations possibly representing 2 subdorsal and 2 subventral papillae and 2 lateral amphids. About 2 hours after hatching, larvae 228μ to 265μ long and 13μ to 15μ in maximum width; posterior portion terminating in a long, slender, pointed tail, 41μ to 57μ long. According to Lucker, larvae, as a rule, still in first stage when about 325μ long.

Cuticle.—Very thin, transparent, and without transverse striations; apparently set off from body at anterior end by a small constriction (fig. 29, *D*).

Alimentary tract.—Mouth aperture leading into a cylindrical buccal cavity; its walls, in optical section, appearing as two sharp refringent rods (fig. 29, *D*); a short and fibrous structure (fig. 29, *D*) interpolated posterior to buccal cavity and anterior to esophagus. Esophagus rhabditiform and very muscular, 64μ to 95μ long in larvae about 3 hours after hatching. Intestine somewhat granular, its individual cells not easily differentiated; lumen of intestine in lateral view usually straight (fig. 29, *J*), differing in this respect from corresponding larvae of strongyles, which usually have a lumen with a sinuous outline; intestine connected posteriorly with a short rectum.

Nervous system.—Nerve ring encircling narrow portion of esophagus; 41μ to 60μ from anterior end in larvae about 3 hours after hatching.

Excretory system.—Excretory pore 64μ to 68μ from anterior end and leading into a short, narrow duct.

Genital primordium.—Represented by a small elliptical body ventral in position, near equator of body; 117μ to 140μ from anterior end in larvae about 3 hours after hatching. According to Lucker, genital primordium 10μ to 15μ long at time of first molt.

SECOND-STAGE LARVA

General morphology of second-stage larvae presumably similar to that of first-stage larvae. Lucker states that size attained by these larvae is variable, depending to some extent upon environmental condition during the period of feeding and growth; ordinarily maximum length is about 450μ to 550μ during process of second molt. Genital primordium 10μ to 17μ long.

THIRD-STAGE LARVA (STRONGYLIFORM)

Shape and size.—Body very slender, tapering slightly anteriorly and more so posteriorly (fig. 29, *N*); head end appearing very light in color, the color setting it off from the more granular posterior portion of the body (fig. 29, *G*). The extremely small size of the larva has led several investigators to speculate on the structure of the head. Perroncito (*87*) and Schuurmans Stekhoven (*107*) were of the opinion that the strongyliform larva possesses 3 lips. Kreis (*55*) states that the strongyliform larva of *S. simiae* possesses 4 indistinctly developed lips. According to the observations of the writer, the en face view of the head of *S. ransomi* shows 2 lateral slightly raised elevations, surrounded by 2 subdorsal and 2 subventral papillae and 2 lateral amphids (fig. 29, *H*). Tail shorter than in previous stage, 68μ to 76μ long, and terminating in the characteristic 3 small processes, 2 dorsal and 1 ventral (fig. 29, *L* and *M*); the latter observation is in opposition to that of previous reports in which the tip of the tail of third-stage *Strongyloides* larvae is described as notched, with only 2 processes

Size of third-stage larvae is apparently dependent on the nutritive properties of the medium in which they grow. Schwartz and Alicata (*110*) reported that when these larvae were grown in a feces culture, they were 504μ to 635μ long by 15μ to 19μ wide; in a culture containing a small quantity of water and very little fecal decoction, the writer found that they were 405μ to 420μ long by 13μ wide.

Cuticle.—Thin, transparent, with very fine transverse striations.

Alimentary tract.—Oral opening elongated dorsoventrally (fig. 29, *H*), opening into a narrow lumen connecting posteriorly with a small and distinct buccal cavity (fig. 29, *G*). Esophagus slender and strongyliform, 250μ to 258μ long, occupying about one-half the entire length of body; inconspicuous sphincter at union of esophagus and intestine. Intestinal cells slightly granular, cell walls inconspicuous; intestine connecting posteriorly with a short rectum.

Nervous system.—Nerve ring very inconspicuous, encircling esophagus at union of anterior and middle thirds, 87μ to 90μ from anterior end.

Excretory system.—Excretory pore very inconspicuous, 102μ to 114μ from anterior end.

Genital primordium.—Somewhat elliptical in shape, about 17μ long, and 310μ to 330μ from anterior end.

Description of Larval Stages Undergoing Indirect Development

FIRST-STAGE LARVA

First-stage larva presumably rhabditiform like corresponding larva of direct cycle. According to Lucker, larvae distinguishable from first-stage larvae of direct cycle by possession of a large genital primordium, 15μ to 26μ long in larvae 230μ to 350μ long. Contrast in size of genital primordium in first-stage larvae of the two cycles of development previously noted by Schuurmans Stekhoven (*107*) in larvae of *Strongyloides stercoralis.*

SECOND-STAGE LARVA

Second-stage larva presumably rhabditiform and similar in shape to first-stage larva. According to Lucker, larvae, tentatively determined by him as second-stage larvae, 300μ to 450μ long by 20μ to 25μ wide. Genital primordium 25μ to 70μ long; tail 60μ to 78μ long.

THIRD-STAGE LARVA

Third-stage larva presumably rhabditiform and similar in shape to those of previous stages. According to Lucker, larvae, tentatively determined by him as third-stage larvae, 420μ to 550μ long by 25μ to 31μ wide. Genital primordium 60μ to 160μ long; tail 70μ to 80μ long.

FOURTH-STAGE LARVA

Fourth-stage larva presumably rhabditiform and similar in shape to previous stages; according to Lucker, sex can be differentiated at this stage. Males about 750μ long, possessing a completely formed spicular apparatus; females 750μ to 875μ long just preceding last molt; uterus and ovaries at this stage more or less completely formed.

FIFTH OR ADULT STAGE

Male.—According to Schwartz and Alicata (*110*), males (fig. 30, *D*) 868μ to 899μ long; smaller specimens 748μ long by 38μ wide also seen by writer. Body nearly equal in diameter for most of its length, tapering toward anterior and posterior ends. In en face view, head with 2 lateral liplike elevations, each possessing 1 subdorsal and 1 subventral papilla and a lateral amphid (fig. 30, *A*). According to Schuurmans Stekhoven (*107*), free-living adults of *Strongyloides stercoralis* with 3 lips; this investigator did not study head in en face view. Head of *S. ransomi*, in lateral view, distinctly set off from rest of body by shallow constriction (fig. 30, *B*). Oral opening leading into wide buccal cavity lined with thick walls (fig. 30, *B* and *C*). A short fibrous structure 9μ long interpolated anterior to esophagus and set off from it by a constriction. Esophagus very muscular, rhabditiform; in a male specimen 748μ long, esophagus 121μ long. Two spicules present; according to Schwartz and Alicata, each spicule 26μ to 29μ long, shaped like a curved blade (fig. 30, *F* and *G*). Gubernaculum 18μ to 22μ long by 9.4μ wide. Several papillae present at posterior portion of body, namely, 2 pairs preanal and 3 pairs postanal; also 1 papillalike elevation present above cloacal opening (fig. 30, *F*). Tail somewhat slender and pointed, 83μ to 90μ long.

Female.—According to Schwartz and Alicata (*110*), females (fig. 30, *G*) 1 to 1.1 mm long by 62μ in maximum width; specimens 0.8 to 1.3 mm long also observed by the writer. Shape of body and structure of head and digestive tract as in free-living adult males. Vulva with salient lips, located near equator of body. Gravid females containing several shelled eggs in various degrees of segmentation. Tail somewhat slender and pointed, 150μ to 158μ long.

Description of Egg, Embryo, and Larval Stages from Progeny of Free-Living Generation

EGG

Shape of eggs similar to those of parasitic females. In a series of measurements involving 25 eggs, length 45μ to 60μ, width 26μ to 34μ; usually embryonated

when deposited by gravid females; frequently old females fail to oviposit and their eggs hatch in the uterus.

EMBRYO

Embryo morphologically similar to embryo derived from egg of parasitic female.

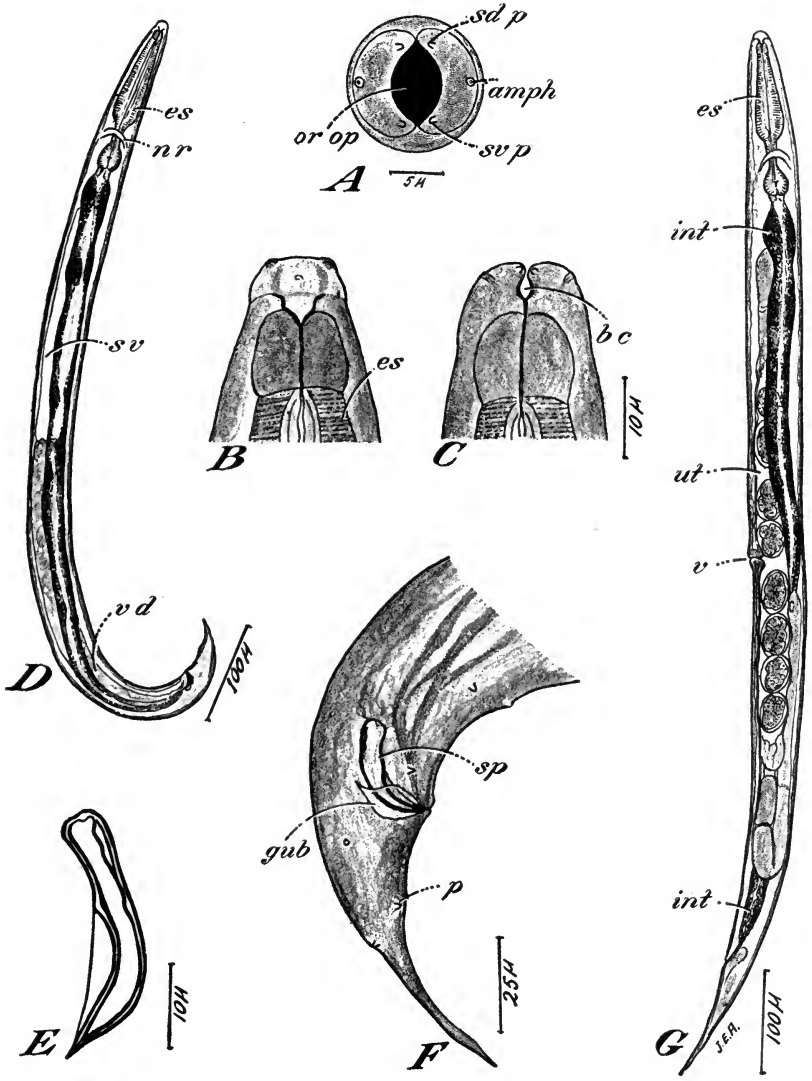

FIGURE 30.—ADULT FREE-LIVING MALES AND FEMALES OF STRONGYLOIDES RANSOMI.

Male: *D*, Lateral view; *E*, view of spicule; *F*, posterior portion of male, lateral view.
Female: *A*, Anterior end, en face view; *B*, anterior end, lateral view; *C*, anterior end, dorsal view; *G*, lateral view of female.

FIRST-, SECOND-, AND THIRD-STAGE LARVAE

These three larval stages, according to observations by Lucker, morphologically similar to corresponding stages in direct cycle.

Development of Strongyloides Ransomi Outside the Host

The development of the various stages of *Strongyloides ransomi* outside the host, in accordance with information obtained by Lucker, is as follows:

DIRECT DEVELOPMENT OF THIRD-STAGE LARVAE FROM EGGS OF PARASITIC FEMALES

At room temperature (22° to 24° C.), eggs of parasitic females hatch in from 4 to 18 hours and the larvae undergo the first molt from 12 to 18 hours later. Second-stage larvae, after a period of growth, molt a second time in less than 48 hours after incubation (fig. 29, *K*); after the second molt the larvae are in the third stage.

INDIRECT DEVELOPMENT OF FREE-LIVING ADULT MALES AND FEMALES FROM EGGS OF PARASITIC FEMALES

At room temperature (22° to 24° C.), eggs of parasitic females hatch in from 4 to 18 hours and larvae undergo the first molt about 10 hours after hatching (fig. 29, *B* and *E*). Second-stage larvae, after a period of growth, undergo a second molt from 12 to 14 hours after the first molt. The time required for the third and fourth molt is not stated; however, Lucker noted adult free-living males and females from 36 to 48 hours after incubation.

DEVELOPMENT OF THIRD-STAGE LARVAE FROM EGGS OF FREE-LIVING FEMALES

Eggs deposited by free-living females usually hatch in 12 hours. The first molt in a water medium is apparently variable, and may require about 48 hours, especially when food is scarce. Second-stage larvae apparently molt from 48 to 60 hours after incubation, as that was the period when third-stage larvae were noted by Lucker in water cultures.

Observations on Effects of Environment

SKIN PENETRATION

Lucker has shown that third-stage larvae of *Strongyloides ransomi* are capable of penetrating the skin of live pigs and rabbits, this resulting in an intestinal infestation.

RESISTANCE TO DESICCATION

A small drop of water containing a number of third-stage larvae was placed on each of several glass slides. At the moment the water evaporated, the time was noted, and the slides remained exposed at room temperature for various periods as shown in table 35. At the expiration of the desired lapse of time, a few drops of water were added to the dried larvae, and the preparations were examined at various intervals for about 24 hours.

Table 35 shows that exposure of 5 to 10 minutes to air drying destroyed the vitality of most larvae, and a 20-minutes' exposure proved fatal to all larvae.

TABLE 35.—*Results of observations on the resistance of third-stage larvae of Strongyloides ransomi to air drying at room temperature (24° C.)*

Number of larvae used	Duration of exposure	Condition of larvae after addition of water	Number of larvae used	Duration of exposure	Condition of larvae after addition of water
	Minutes			*Minutes*	
10	2	All active.	10	10	9 dead; 1 showed slight movement after 10 minutes, but was dead after 24 hours.
10	5	8 dead; 2 showed slight movement after 10 minutes, but were dead after 24 hours.	15	20	All dead.

REACTION TO COLD

Observations were made on the effects of various low temperatures on the third-stage larvae of *Strongyloides ransomi*. Each record is based on observations involving about 1,000 larvae. During the course of the experiment the larvae were kept in glass tubes containing moist animal charcoal. The results are given in table 36, which shows that exposure of 6 hours to −15° C. destroyed the vitality of some larvae, and an exposure of 25 hours to that temperature destroyed all the larvae.

TABLE 36.—*Effects of low temperature (−15° C.) on the infective larvae of Strongyloides ransomi, each culture involving about 1,000 larvae*

Culture no.	Period of refrigeration	Condition of larvae at termination of exposure	Culture no.	Period of refrigeration	Condition of larvae at termination of exposure
	Hours			*Hours*	
1	6	Majority of larvae moved slowly.	3	22	About 50 percent showed slight movement; others dead.
2	18	About 50 percent showed slight movement; others dead.	4	25	All larvae dead.
			5	30	Do.

LONGEVITY OF LARVAE IN FECES AT ROOM TEMPERATURE

General observations have indicated that the life of third-stage larvae of *Strongyloides* is somewhat short. Bruns (*14*) found that he could keep third-stage larvae of *Strongyloides* alive for 20 days. Schuurmans Stekhoven (*107*) reported that under favorable conditions of humidity and temperature, the longevity of *S. stercoralis* did not exceed 3 to 4 weeks. In 2 cases the writer has noted that the length of life of *S. ransomi* in swine feces kept in 1-quart glass jars did not exceed 11 to 13 days. This indicates that the life of the third-stage larva under field conditions is probably short. Such short duration of life is not surprising, however, since these larvae are not protected by a sheath as are third-stage larvae of most strongyle nematodes.

COMPARATIVE MORPHOLOGY OF EGGS AND THIRD-STAGE LARVAE OF SOME NEMATODES OCCURRING IN SWINE

As already indicated, the eggs and third-stage larvae of each of the various species of nematodes parasitic in swine can be differentiated from one another in most cases. The various differential characters are given in tables 37 and 38.

TABLE 37.—*Comparison of eggs of some swine nematodes soon after eggs are deposited*

EGGS WHICH USUALLY DO NOT HATCH OUTSIDE OF HOST

Nematode	Measurements of egg	Characteristics of eggshell	Degree of development and characteristics of egg when deposited
	Microns		
Gongylonema pulchrum	57–59 by 30–34	Slightly thick, smooth, colorless.	With fully formed embryo. Cephalic portion with rows of spines; anterior end of ventral portion with 2 small hooks; posterior hook about 3μ long.
Ascarops strongylina	41–45 by 22–26	Thick; surface with small punctations; colorless.	As in *G. pulchrum*, except posterior hook about 1.7μ long.

TABLE 37.—*Comparison of eggs of some swine nematodes soon after eggs are deposited*—Continued

EGGS WHICH USUALLY DO NOT HATCH OUTSIDE OF HOST—Continued

Nematode	Measurements of egg	Characteristics of eggshell	Degree of development and characteristics of egg when deposited
	Microns		
Physocephalus sexalatus	41–45 by 22–26	Thick; surface with small punctations; colorless.	As in *G. pulchrum*.
Metastrongylus salmi	43–57 by 38–41	Thick; surface slightly mammilated; dark grayish.	With fully formed embryo; spines or hooks absent.
Metastrongylus elongatus	45–57 by 38–41	do	Do.
Choerostrongylus pudendotectus	60–64 by 43–45	do	Do.
Ascaris suum	68–84 by 50–76	Thick; surface usually coarsely mammilated; brownish yellow.	Usually in 1-cell stage.
Trichuris suis	60–68 by 28–31	Thick; surface smooth; lemon shaped; dark brown.	In 1-cell stage.

EGGS WHICH HATCH OUTSIDE OF HOST

Hyostrongylus rubidus	60–76 by 31–38	Thin; surface smooth, colorless.	In early tadpole stage.
Oesophagostomum dentatum	61–83 by 38–53	Thin; surface smooth, colorless.	Usually with 8 to 16 cells.
Stephanurus dentatus	91–114 by 53–65	do	With about 32 to 64 cells.
Strongyloides ransomi	53–57 by 30–34	do	In late tadpole stage to early vermiform embryo stage.

TABLE 38.—*Comparison of third-stage (infective) larvae of some nematodes occurring in swine*

Nematode	Size	Differential characters	Location
Gongylonema pulchrum	1.90–2.45 mm by 50–68μ.	Lateral border of mouth projects outward; esophagus divided into 2 parts; tail with 2 or 4 small digitiform processes.	Encysted in insects or accidentally, possibly in vertebrates.
Ascarops strongylina	1.91–2.32 mm by 53–91μ.	Head with 2 dorsoventral liplike elevations; esophagus divided into 2 parts; tip of tail with smooth knob.	Encysted in insects or, accidentally, in vertebrates.
Physocephalus sexalatus	1.35–1.60 mm by 60–68μ.	Head and esophagus as in *A. strongylina;* tip of tail with many small digitiform processes.	Do.
Metastrongylus salmi	550–630μ by 26μ	Head rounded; esophagus strongyliform; near end of tail, 2 somewhat indistinct notches.	Usually in esophageal wall or blood vessels of annelid s ensheathed.
Metastrongylus elongatus	625–665μ by 26μ	Head and esophagus as in *M. salmi;* near end of tail, usually 2 deep notches.	Do.
Choerostrongylus pudendotectus	600–655μ by 26μ	As in *M. salmi*	Do.
Hyostrongylus rubidus	715–735μ by 22μ	Head rounded; esophagus strongyliform; buccal cavity spearhead-shaped; tip of tail with a digitiform process.	Usually in feces; ensheathed.
Oesophagostomum dentatum	500–532μ by 26μ	Head and esophagus as in *H. rubidus;* buccal cavity with lining drawn out into thin strands of interlacing fibers; tail somewhat pointed.	Do.
Stephanurus dentatus	518–610μ by 24–26μ	Head and esophagus as in *H. rubidus;* buccal cavity spindle-shaped; tip of tail rounded.	Do.
Strongyloides ransomi	504–635μ by 15–19μ	Head rounded; esophagus slender, occupying about one-half length of worm; tip of tail with 3 small pointed processes.	Usually in feces; exsheathed.

SUMMARY

A study was made of the early developmental stages of the following nematodes parasitic in swine: *Gongylonema pulchrum*, *Ascarops strongylina*, *Physocephalus sexalatus*, *Metastrongylus salmi*, *M. elongatus*, *Choerostrongylus pudendotectus*, *Ascaris suum*, *Trichuris suis*, *Hyostrongylus rubidus*, *Oesophagostomum dentatum*, *Stephanurus dentatus*, and *Strongyloides ransomi*. For two of the nematodes, however, *G. pulchrum* and *H. rubidus*, observations on the stages in the definitive host are also discussed briefly. The nomenclature of each parasite, its host relationship, geographic distribution, morphology, and bionomics of its early stages are given.

When fed to roaches, eggs of *Gongylonema pulchrum* hatched within 24 hours and the larvae developed to the infective or third stage in about 32 days. These larvae encysted within the sarcoplasm of the muscle fibers of the insect host. When fed to guinea pigs, third-stage larvae promptly penetrated the tissue at the junction of the stomach and esophagus, usually entering the wall of the esophagus in this region, and migrated under the linings of the esophagus and of the oral cavity. Under these linings the worms were found sexually mature 70 days after experimental infection. Eggs of *G. pulchrum* contained viable embryos after 4 months' exposure to outdoor-conditions at from −6.6° to 37.7° C., and after being kept 4 months at room temperature (22° to 24°). Three new intermediate hosts for this parasite are reported in this bulletin, namely, *Aphodius lividus*, *Dermestes vulpinus*, and *Parcoblatta* sp.

When fed to beetles, eggs of *Ascarops strongylina* hatched within 24 hours, and the larvae developed to the infective stage in about 29 days. Eggs of this parasite contained viable embryos after 20 days' exposure at from −4° to 2° C., and after being kept 4 months at room temperature (22° to 24°). Two new intermediate hosts are reported in this bulletin for this parasite, namely, *Aphodius granarius* and *Passalus cornutus*.

When fed to beetles, eggs of *Physocephalus sexalatus* hatched within 24 hours and developed to the infective stage in 36 days. Eggs of this parasite contained viable embryos after being kept at a temperature of from −4° to 2° C. for 20 days. Two new intermediate hosts for this parasite are reported in this bulletin, namely, *Ataenius cognatus* and *Passalus cornutus*.

The larvae of *Metastrongylus salmi* have been successfully reared to the third stage in earthworms, *Lumbricus terrestris* and *Helodrilus caliginosus* var. *trapezoides*. Third-stage larvae may remain alive in the body of the earthworm for at least 4 months.

In a study of the development of *Metastrongylus elongatus* and *Choerostrongylus pudendotectus*, third-stage larvae of these parasites have been found in the bodies of earthworms as late as 9 months after experimental infection. Lungworm eggs eliminated with the feces of swine do not hatch outside the host. The surface of the eggshell is corrugated.

Eggs of *Ascaris suum* were found to reach the infective stage in 16 days at 33° C., in 18 days at 30°, and in 28 days at 22° to 24°. The infectivity of the egg was determined by the molting of the embryo within the shell and by the ability of the eggs to produce

an infestation when fed to guinea pigs. Nonmolted embryos were not infective to guinea pigs.

Eggs of *Trichuris suis* were found to contain fully developed embryos in 18 days when kept at 37.5° C., in 22 days at 33°, in 54 days at room temperature (22° to 24°), and in about 7 months outdoors when kept underground; the temperature outdoors during the 7 months was from 6.1° to 24.5°.

Eggs of *Hyostrongylus rubidus* cultured at room temperature hatched and the larvae developed to the infective stage in 7 days. Third-stage larvae fed to guinea pigs developed in the stomach without undergoing further migration and reached the fifth stage in from 17 to 19 days. In the preparasitic larval stages of *H. rubidus* sex was differentiated by the position of the posterior cell of four giant cells in the body cavity of the larva. Preparasitic larvae in which this giant cell is anterior to the genital primordium develop into males, whereas those in which this cell is slightly lateral or posterior to the genital primordium develop into females. The general development of the male and female reproductive systems was traced in the four larval stages of this parasite. Third-stage larvae of *H. rubidus* showed the following characteristics: (1) They failed to penetrate the skin of young rats or guinea pigs; (2) they were resistant to a temperature of 3° to 5° C. for 6 days, but not to a temperature of −5° to 1° for 30 days; (3) their vitality was destroyed when they were kept at −20° for 9 hours; (4) they were killed when subjected to air drying for 4 hours; (5) in water-charcoal culture, they survived for 2½ months but not for 3½ months.

Eggs of *Oesophagostomum dentatum* cultured at room temperature hatched, and the larvae developed to the infective stage in about 6 days. Third-stage larvae of *O. dentatum* showed the following characteristics: (1) They failed to penetrate the skin of young rats under experimental condition; (2) some larvae showed signs of life when exposed to −19° to −29° C. for 10 days; however, their vitality was destroyed when kept at a temperature of −15° to −29° for 31 days; (3) larvae were killed when subjected to air drying for 22 hours; (4) larvae kept in water-charcoal culture for about 10 months appeared normal.

Eggs of *Stephanurus dentatus* cultured at room temperature (22° to 24° C.), hatched and the larvae developed to the infective stage in about 5 days. Third-stage larvae have been found to possess the following characteristics: (1) They failed to penetrate the skin of 2-day-old rats; (2) they succumbed after 1 hour's exposure to air drying at room temperature; (3) their vitality was not destroyed when they were exposed for 6 hours at −19° but an exposure for 9 hours at that temperature proved fatal; (4) they were found to be normal after being kept in water-and-charcoal media for 40 days.

The life of *Strongyloides ransomi* in feces-and-charcoal cultures kept in bottles at room temperature did not exceed 11 to 13 days. Strongyliform larvae were found to perish when subjected to air drying for about 20 minutes, and when subjected to −15° C. for 25 days.

It was determined that the shape of the buccal cavity usually serves to differentiate between the third-stage larvae of the various parasites discussed in this bulletin.

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REDUCING DECAY IN CITRUS FRUITS WITH BORAX

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INTRODUCTION

Although the production of citrus fruits is confined to relatively small areas in a few States, the market for the crop is Nation-wide and there is a growing export trade as well. The losses from decay developing between the time the fruit is harvested and consumed are often serious and greatly complicate the marketing program.

FUNGI CAUSING DECAY

Citrus fruits are subject to a number of types of rot during the marketing period. Some of these, the ones caused by species of *Penicillium* for example, occur wherever citrus fruits are grown, while others are less generally distributed. In the Gulf States two major classes of rots occur: (1) The green and blue molds caused by *P. digitatum* Sacc. and *P. italicum* Wehmer, the former being by far the more common; and (2) the stem-end rots caused by *Diplodia natalensis* Evans and the *Phomopsis* stage of *Diaporthe citri* Wolf. The latter fungus also is the cause of the rind blemish known as melanose. In the more arid citrus-growing districts of California and Arizona the stem-end rots are found only occasionally and so far have been reported only on lemons. Several other fungi, such as *Colletotrichum*, *Alternaria*, *Rhizopus*, *Aspergillus*, *Oospora*, *Fusa-*

rium, etc., are isolated occasionally from decaying fruit from all producing districts.

For a long time the penicillium rots were the ones most commonly found and caused the greatest loss, but at the present time this form of decay represents only a relatively small part of the total. This improvement in conditions is largely because of an application of the fundamental principles of fruit handling developed by Powell and his associates.[1] Improvements in clippers have greatly reduced clipper cuts, and overfilling of field or lug boxes resulting in box bruises is usually avoided. The fruit, therefore, is now harvested and delivered to the packing houses in much better condition than formerly. Packing houses are now being improved as to cleanliness and sanitary conditions, thereby reducing the chances for contamination; fruit is being handled and packed more carefully; refrigeration is in more general use; and last, but not least, antiseptic fruit washes, such as borax and carbonate of soda, have come into general use and have played an important part in delaying or actually preventing penicillium rots.

The beneficial effects from the adoption of these improved practices are principally apparent in the reduction of penicillium rots, which have thus been relegated to comparatively minor importance in the handling of a citrus crop; consequently, in regions where stem-end rot fungi occur, these more slowly developing decays are now of primary importance. It seems probable that much of the fruit which formerly decayed with *Penicillium* was also actually infected with stem-end rot, but that the blue or green molds destroyed it before stem-end rot had time to develop.

The blue and green molds differ radically from the stem-end rots, not only in gross appearance but in pathological aspects as well. For the most part, penicillium rots result from infections established through mechanical injuries, such as clipper cuts, box bruises, etc., sustained during the harvesting (fig. 1) and packing operations, and, in addition, infection by *Penicillium italicum* also passes from a decaying fruit to an uninjured one by contact. Most of the injuries that afford entrance for the penicillium fungi occur before the fruit reaches the packing house. One of the most important causes of such injuries is the use of a high bulge pack as demanded by the trade. This generally results in such severe bruising, especially of the top layer, that penicillium rots gain ready entrance. Susceptibility to stem-end rot varies from grove to grove. Fruit from young trees is less likely to be affected than that from old trees. Fruit produced where there is considerable open space between the trees (fig. 2) develops stem-end rot much less rapidly than that produced on thickly growing trees (fig. 3), other things being equal. While the exact mode and time of infection by the stem-end rot organisms is not definitely known, for all practical purposes they may be regarded as causing incipient infection while the fruit is on the tree, being in or on the stem or stem parts at time of harvest. However, they may not develop to the point of

[1] POWELL, G. H., STUBENRAUCH, A. V., TENNY, L. S., EUSTACE, H. J., HOSFORD, G. W., and WHITE, H. M. THE DECAY OF ORANGES WHILE IN TRANSIT FROM CALIFORNIA. U. S. Dept. Agr., Bur. Plant Indus. Bull. 123, 79 pp., illus. 1908.

FIGURE 1.—Picking crew at work in a Florida orange grove. The boxes are overfilled so that bruising of the top fruit will result when they are stacked on the trucks and in the packing house. While such bruising should be avoided to reduce penicillium rot, a borax bath given immediately upon arrival at the packing house will greatly retard the decay.

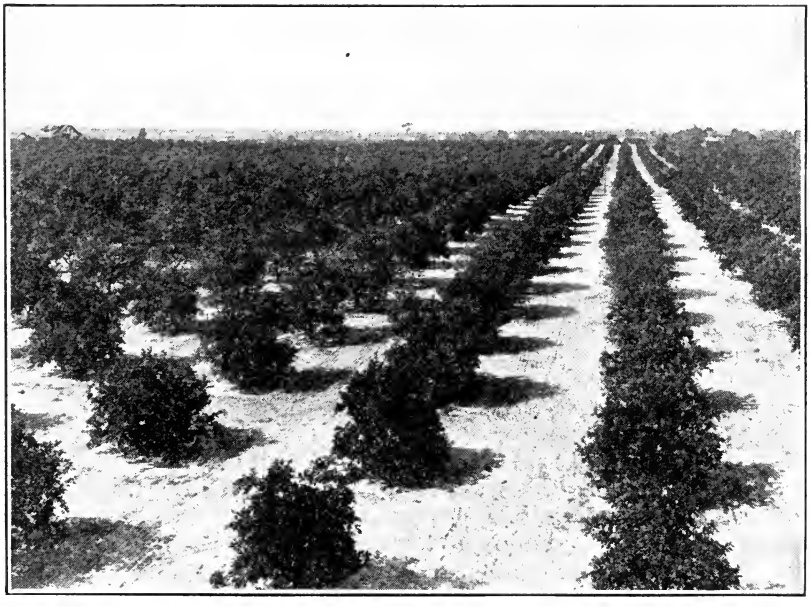

FIGURE 2.—A young orange grove in Florida. Fruit produced on young trees which have considerable open space between them and which are generally free from much deadwood develops stem-end rot much less rapidly than that from old trees which have grown together and which have many sources of infection in deadwood.

becoming visible for several days after packing or until after the fruit has entered shipment or reached its market destination. The resulting losses react not only on the grower or shipper but also on the receiver, the retail merchant, and the ultimate consumer as well, thus developing a lack of confidence all along the line which is reflected in the price that the fruit will bring.

COMMON REMEDIAL PRACTICES

In the control of various kinds of citrus rots during the marketing process, various procedures are followed, depending upon the peculiarities of the causal organism. In general, these measures may be divided into five classes: (1) Prevention of infection in the grove through sanitation, including the removal of the sources of infec-

FIGURE 3.—Old orange trees with branches interlaced afford good conditions for the development of stem-end rot, there ordinarily being more deadwood in the trees and less air circulation to dry out moisture than in trees like those shown in figure 2.

tion; (2) careful mechanical handling at all stages of the harvesting and packing operation, in order to reduce the number of lesions which may afford ready entrance for decay organisms, particularly the penicillium rots; (3) the removal of stem "buttons" while the fruit is being packed, in order to check those decays that enter the fruit through the stem or stem parts; (4) inhibiting the development of decay organisms that may have found lodgment on the fruit or that possibly may have advanced slightly into the tissues of the fruit, by the use of heat and/or mild antiseptics such as borax, carbonate of soda, etc., applied at some stage in the packing operations; and (5) checking the development of the decay organisms by the use of refrigeration after the fruit is packed. There are definite limitations to the effectiveness of each of these treatments.

Grove sanitation, involving both pruning and spraying, has been shown by Fulton and Bowman,[2] Reichert and Hellinger,[3] Reichert,[4] and others, to be helpful in the reduction of stem-end rot. However, cost considered, it is not believed to be effective enough to be generally practicable as a means of stem-end rot control for commercial growers. It has little or no effect upon penicillium rots, but both pruning and spraying must be done as a part of every well-rounded program of grove operations.

Careful handling is the very foundation of decay prevention, especially in the case of penicillium rots. Other decay-control treatments are made more effective if the fruit has been carefully handled to prevent mechanical injuries. Careful handling is of the utmost importance in all commercial operations.

Disbuttoning the fruit during the packing operation is fairly effective in the reduction of stem-end rot, but it is not effective against blue mold or green mold; in fact, this practice may increase loss from penicillium rots when the rind tissues are torn or injured in the disbuttoning operation. This process usually requires a preparatory treatment to loosen the buttons, the greater portion of which at times may then be removed by passing the fruit through a brushing machine fitted with rather stiff bristles. A spoonlike instrument operated by hand is also used sometimes to remove the stems. While ethylene gas may be used to loosen the buttons, the treatment has not been found to be generally effective with different kinds of fruit during the principal part of the shipping season. When blue mold is prevalent, disbuttoned fruit may require subsequent treatment with a mild antiseptic, or it may need to be held at low temperatures to prevent excessive development of this type of decay which enters the fruit through wounds that may be made during the disbuttoning process. At best, disbuttoning is a laborious operation that is hardly compatible with mass production and high labor costs, although it may be commercially practicable in Florida during the forepart of the shipping season when ethylene is most effective in loosening stem buttons, causing a large percentage of them to fall out during the usual washing and polishing treatment, and when fruit movement to market is at its lowest ebb. At this season fruit prices are usually high, thereby justifying maximum financial investment in decay reduction. The treatment, however, is reported to be in successful commercial operation in Jamaica where labor is cheap and production is rather limited.

Exposure for a few minutes to a water bath heated to 110° to 120° F. is effective against certain rots (brown rot, botrytis rot, etc.), but the method as ordinarily employed is only partially successful in the control of blue mold and stem-end rot. Fulton and Bowman [5] showed that a heated borax solution is capable of reducing both blue-mold rot and stem-end rot of Florida citrus fruits, and

[2] FULTON, H. R., and BOWMAN, J. J. EFFECT OF SPRAYING WITH FUNGICIDES ON THE KEEPING QUALITY OF FLORIDA CITRUS FRUITS. U. S. Dept. Agr. Circ. 409, 14 pp., illus. 1927.

[3] REICHERT, I., and HELLINGER, E. FURTHER EXPERIMENTS ON THE CONTROL OF DIPLODIA STEM-END ROT OF CITRUS BY PRUNING AND SPRAYING. Hadar 5: 142–143. 1932.

[4] REICHERT, I. THE INVESTIGATION OF FRUIT ROTS SUPPORTED BY THE EMPIRE MARKETING BOARD. Hadar 5: 236–238. 1932.

[5] FULTON, H. R., and BOWMAN, J. J. PRELIMINARY RESULTS WITH THE BORAX TREATMENT OF CITRUS FRUITS FOR THE PREVENTION OF BLUE MOLD ROT. Jour. Agr. Research 28: 961–968, illus. 1924.

Barger and Hawkins [6] reported the same general results on penicillium decay in California oranges. Subsequently, other mild antiseptics such as boric acid and sodium carbonate have come into general use, being applied during the washing process immediately before packing. Of the various antiseptics now in use, none excels borax in general all-round effectiveness for commercial use, especially when the solution is applied at a temperature of 100° to 110°. During the past few years the use of borax in this manner has increased very markedly.

The frequently serious prevalence of stem-end rot in fruit arriving on the market seems to indicate that the application of antiseptics is sometimes delayed until after the causal organism has advanced too deeply into the fruit to be reached by the chemical. This is especially the case with fruit that has been harvested several days and also with that undergoing the usual coloring process which affords an environment especially favorable to the development of these decay organisms before treatment with borax.

Refrigeration, aside from keeping fruit in a fresh condition, does little more than delay the development of decay. It does not permanently prevent decay, since slow growth of decay organisms occurs within the tissues, particularly with the *Penicillium* species, at ordinary refrigeration temperatures. Prolonged refrigeration may even weaken the fruit, thereby permitting a somewhat more rapid spoilage after the removal from low temperatures. Upon removal from cold storage the fruit frequently sweats because of the difference between the fruit temperature and that of the air, which causes a condensation of moisture on the surface. This is very undesirable because it provides conditions favorable for immediate infection and the rapid development of decay.

EXPERIMENTAL WORK

In the fall of 1931 experimental work was begun at Orlando, Fla., to determine whether a more effective control of stem-end rot could be obtained by the use of borax or some other cheap antiseptic applied in the packing house during the handling operations. Insofar as stem-end rot is concerned, the available evidence from commercial experience indicated that the fungi principally concerned in this decay are in a somewhat dormant state in or on the stem or stem parts when the fruit is harvested, and that under conditions of comparatively high temperatures and humidity these organisms are capable of rapidly advancing into the fruit. They advance even more rapidly if the fruit is held in an atmosphere of rather concentrated coloring gases. Working upon this hypothesis, experiments were conducted with antiseptics applied as soon as commercially practicable after harvesting, that is, immediately after the fruit reached the packing house in comparison with delayed application, as in the case of the usual commercial practice in which the coloring treatment was given before application of the antiseptic. In the coloring treatment the fruit is not only exposed to coloring gases from 24 to 60 hours or longer but is held under conditions of

[6] BARGER, W. R., and HAWKINS, L. A. BORAX AS A DISINFECTANT FOR CITRUS FRUITS. Jour. Agr. Research 30: 189–192. 1925.

high atmospheric temperature and humidity as well—ideal conditions for the development of stem-end rot organisms. The studies reported herein were directed particularly to the solution of the decay problem presented by these conditions.

METHODS

All of the fruit used in these experiments was harvested, hauled, and otherwise handled in accordance with the practice at the better commercial packing houses. Upon its arrival at the laboratory the fruit was divided into lots of about 50 pounds each for oranges and grapefruit and about 25 pounds for tangerines. The number of fruits per lot varied, depending on the size. Early in the season the number of fruits per lot was greater than later when the fruits were larger. No attempts were made to grade the fruit or sort for defects, except to discard those badly damaged during the handling operation. A 5-percent borax solution was used as the standard unless otherwise noted. The method of application was by dipping or immersing the fruit for the specified length of time in the antiseptic, and unless otherwise noted the fruit was allowed to dry in the open air for a few minutes to an hour or more, depending on atmospheric conditions. Unless otherwise noted, also, the residue from the antiseptic solutions was left on the fruit several days and was then removed by rinsing in water, after which the fruit was allowed to dry. Thus, sometimes several hours elapsed before the fruit could be placed in the holding room. This room was maintained at a temperature of about 70° F. and 82 to 88 percent relative humidity. In all cases, the fruit was dried before being transferred to the holding room. Periodically all lots of fruits were carefully examined for decay, in accordance with a prearranged schedule, and all rotting fruits were removed. A record of the type and number of fruits affected was first made on the sixth day from the tree and twice weekly during the 30-day holding period.

In these experiments fruit from a large number of groves was used to determine any difference in response that might reasonably be attributed to cultural practices or to varietal characteristics. For the most part, the fruit was produced in the Orlando district, although some of it was produced on the Government reservation near Brooksville, Fla., requiring a haul of about 80 miles. In the latter case, most of the fruit was not given the borax bath until the day after it was picked. Since stem-end rot is not generally serious on fruit from well-kept young groves, but is often severe in the older groves because of the greater prevalence of sources of infection in deadwood, the fruit used in these experiments was taken from old trees, unless otherwise noted.

COMPARISON OF ANTISEPTICS

Experiments were planned to obtain information as to the effect of the concentration of the solution and also as to the comparative effects of the component ions. The following tests were included:

(1) A 5-percent solution of borax, $Na_2B_4O_7.10H_2O$, which was taken as the standard of comparison, since it has been in common use in commercial procedure.
(2) A 5-percent solution of boric acid, H_3BO_3.

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(3) A 3.2-percent solution of boric acid, which contains a concentration of boron ions equivalent to that in a 5-percent solution of borax.
(4) A 5-percent solution of a mixture of 8 parts borax and 1 part boric acid, producing an approximately neutral solution.
(5) A 3.5-percent solution of sodium carbonate, $Na_2CO_3.10H_2O$ which contains the same concentration of sodium ions as found in a 5-percent solution of borax.

The experiments were conducted in October, November, and December 1932, using oranges, grapefruit, and tangerines harvested on four different dates from the Government reservation near Brooksville. The standard procedure in all cases was to dip the fruit into the antiseptic solution for the time indicated and then allow it to dry before subjecting it for 72 hours to the coloring treatment. After coloring, the fruit was washed in clean running water to remove the adhering residue of the antiseptic and was then dried and transferred to a room held at 70° F. for subsequent observation of the rate of decay. The results with oranges, presented in figure 4, are typical of those obtained with grapefruit and tangerines except for the rate of decay, which is usually faster with oranges. The decay during the first 3 weeks was almost exclusively stem-end rot.

It was found that boric acid, alone or in combination with borax, injured the rinds of oranges, grapefruit, and tangerines. This injury was characterized by the development of a brown, discolored, slightly sunken area, usually around the stem and becoming evident after about 16 days' holding. Usually these discolored areas increased in size after prolonged holding. In many instances the fruits thus affected were otherwise sound at the end of the holding period, but in some cases typical stem-end rot or a colletotrichum rot developed. Sodium carbonate produced a brownish rind scald that became noticeable after a few days and increased rapidly as the storage period advanced. Fruit thus affected decayed rapidly with stem-end rot. On the other hand, the use of borax resulted in practically no injury to the fruit and stem-end rot was fairly well controlled, but treatment after coloring was not nearly so effective as when it was applied before coloring. Practically as good results were obtained from only a momentary dip as from the 5-minute bath in the 5-percent borax solution or the neutral borax solution. Similar results were obtained on tangerines, Satsuma oranges, and grapefruit. However, in tests on very ripe oranges in February, stem-end rot was not reduced, and the rind injury noted earlier did not develop. From the results in general it appears that the boron ion in borax or boric acid exerts the principal fungicidal effect.

Further tests were made comparing borax with some of the preparations commonly used as an aid in washing. These consisted principally of sodium metasilicate, soda ash, or trisodium phosphate, etc., in various combinations, as well as sodium polysulphide with and without the aid of soap; sodium hypochlorite and such gases as anhydrous ammonia, nitrogen trichloride, chlorpicrin, and sulphur dioxide applied before or during the coloring process, but none of these seemed to possess decay-retarding properties approaching those of borax, nor was the efficiency of borax increased by the addition of soap. A series of 17 tests was made in the spring of

1934 with oranges that ripened in midseason or later, using borax in comparison with sodium metaborate, potassium metaborate, and potassium tetraborate using a solution in each case with a boron ion concentration equivalent to that in an 8-percent borax solution. The

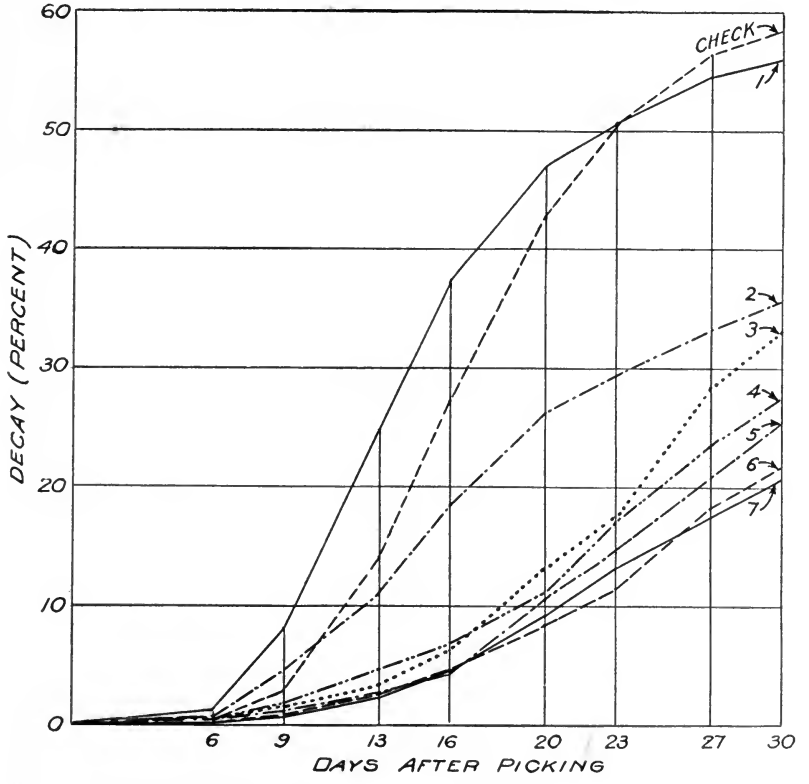

FIGURE 4.—Decay of oranges as influenced by various chemical treatments.

Curve no.	Solution				Treatment before or after coloring
	Solute	Concentration	Temperature	Time of exposure	
		Percent	° *F.*		
1	Sodium carbonate	3.5	80	Dip	Before.
2	Borax	5	110	5 minutes	After.
3	Boric acid	5	80	Dip	Before.
4	do	3.2	80	do	Do.
5	Borax	5	110	5 minutes	Do.
6	Borax and boric acid	5	80	Dip	Do.
7	Borax	5	80	do	Do.
Check	No chemical treatment.				

decay control in all cases was comparable, which is further evidence that it is the boron ion that exerts the principal fungicidal effect. While sodium metaborate caused a slight discoloration of the rind around the stem in some cases, it was not serious enough to be ob-

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jectionable and this chemical may prove to be more satisfactory than borax for use in cool weather, especially where facilities are lacking for keeping the antiseptic solution warm.

CONCENTRATION OF BORAX

Tests were made in November and December 1932 with 32 lots (8 treatments in quadruplicate) of midseason oranges, 32 lots (8 treatments in quadruplicate) of tangerines, and 16 lots (8 treatments in duplicate) of grapefruit, averaging 94, 126, and 35 fruits, respectively, per lot, to determine the best concentration of borax ranging from 2 percent to 12 percent in steps of 2 percent, all being used at 110° F. Both a momentary dip and a 5-minute ex-

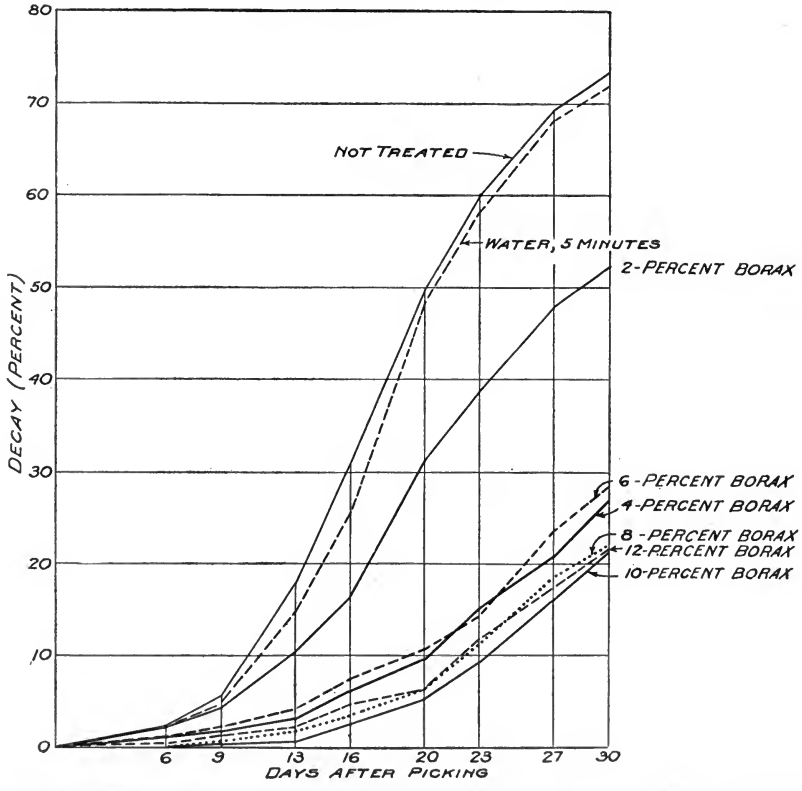

FIGURE 5.—Effect of various concentrations of borax at 110° F. on decay of midseason oranges. Composite results of dip and 5-minute treatments applied before coloring.

posure were tested and compared with similar treatment in water only, at the same temperature. Untreated check fruit was also used for comparison. All of the fruit was then colored in the usual manner and held under comparable conditions at 70° as already described. The comparative effect of the different treatments on decay control in oranges is illustrated in figure 5. Since the results with the momentary dip and the 5-minute bath in the borax solution were practically the same, they have been combined in the preparation of figure 5.

It will be noted that a bath in water at 110° F. for 5 minutes had no appreciable effect in reducing the decay in oranges, indicating that the results in decay control must be due to the borax in solution rather than to the temperature factor in the treatment. It is also apparent that the efficacy of the borax solution increased until the concentration reached about 8 or 10 percent; above that there appeared to be no marked increase in effectiveness in decay control. With tangerines and grapefruit, which normally keep better than oranges, similar results were secured, but the rate of decay was considerably slower. In connection with these results, it should be noted that the fruit was hauled about 80 miles in field boxes in a truck before it was treated. This long haul doubtless

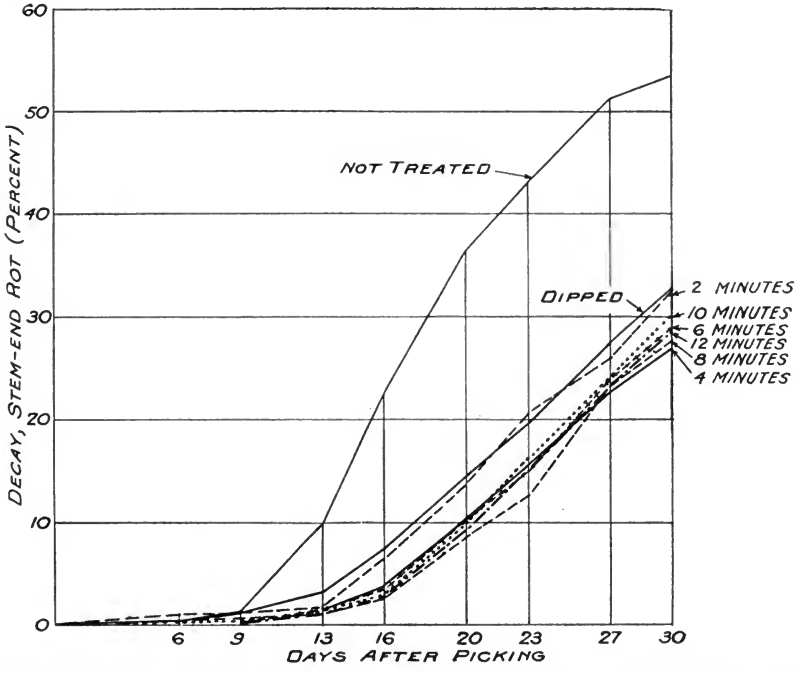

FIGURE 6.—Effect on stem-end rot of exposing citrus fruit for various lengths of time to a 5-percent borax solution at 110° F.; composite of results obtained with oranges, tangerines, and grapefruit. Treatment applied before coloring.

bruised it to a greater or less extent and thereby increased its susceptibility to decay. Under ordinary commercial procedure considerably better results should be expected.

LENGTH OF TREATMENT

During November and December 1932, 18 tests (9 treatments in duplicate) were made with oranges, 18 with tangerines, and 9 with grapefruit, including in all 1,600, 2,180, and 330 fruits, respectively, comparing momentary dips in 5-percent borax with 2-, 4-, 6-, 8-, 10-, and 12-minutes' exposure at 110° F. Similar tests were also made with water at the same temperature (fig. 6).

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With the 5-percent borax solution there was a somewhat better control of stem-end rot from exposures of more than 2 minutes than from the momentary dip or the 2-minute exposure; however, the difference was not sufficiently great to be of practical significance.

Owing to the naturally better keeping quality of tangerines and grapefruit, the difference between the rates of decay in the treated fruit and the checks was not as great as in oranges.

Where water at the same temperature was substituted for the borax solution there was little or no reduction in stem-end rot or blue mold in either oranges or tangerines except from prolonged exposures to 110° F., but even then the reduction was not great enough to be significant. This indicated that the principal factor in suppressing stem-end rot decay was the borax and not the temperature used in the treatment.

TEMPERATURE

The temperature for the borax bath is important principally from the standpoint of the low solubility of borax in cold water. This necessitates the installation of heating equipment in the treating tanks to maintain an effective concentration of borax in solution and to prevent its crystallizing out at night or while cold fruit is being treated.

In order to prove whether the effectiveness of borax is affected by higher temperatures, a series of tests was made. Oranges during 3 seasons and grapefruit and tangerines during 1 season were given 5-minute exposure to the usual 5-percent borax solution at temperatures ranging upward from 80° to 120° F. in steps of 10°, and the results were compared with those from only momentarily dipping the fruit in the borax solutions at the same temperature. The momentary dip was found to be approximately as effective as the longer exposure.

The composite results of 13 tests with an average of 105 fruits each, made at each temperature during three seasons, are shown in figures 7 and 8, the former giving total decay, the latter stem-end rot, in both colored and uncolored oranges. The difference between total decay and stem-end rot consists almost entirely of blue mold, which was generally found to increase during the latter part of the holding period, doubtless due to the extra handling of the fruit in the periodical inspections.

From these results it appears that increasing the temperature of the borax bath was not ordinarily accompanied by a corresponding reduction in decay except at 110° F. In the latter case, the difference was due to reduction in blue-mold rot. Similar results were obtained with tangerines and grapefruit.

Figure 9 shows the composite results of momentarily dipping fruit in 5-percent borax at several temperatures, compared with 5-minute exposures in a 5-percent borax solution at the same temperature. The momentary dip proved to be almost as effective as the 5-minute exposure in reducing stem-end rot, indicating that it is the borax in solution adhering to the fruit as it leaves the bath rather than the action while in the bath that is effective in controlling decay. From this and subsequently presented data it is evident that the fungicidal action is not instantaneous.

Results from using water at corresponding temperatures showed little effect on decay in either oranges or tangerines except at 110° F. or above. At this and higher temperatures a 5-minute exposure was more effective than the momentary dip, particularly in the case of *Penicillium*, indicating that prolonged heat tends to reduce this type of decay.

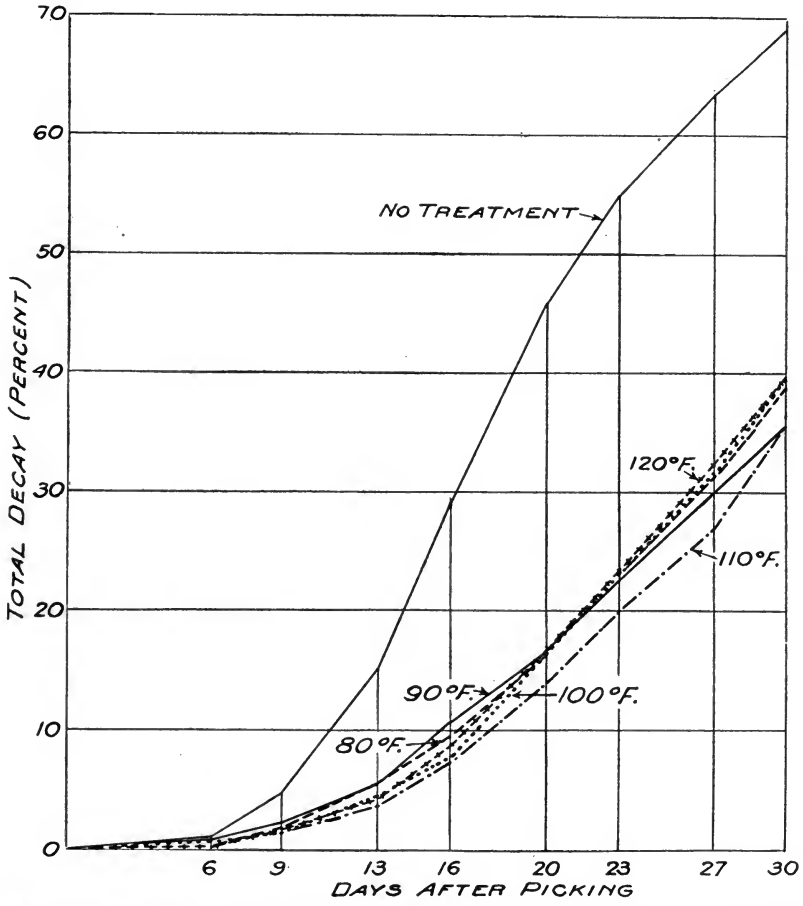

FIGURE 7.—Effect on decay (total) of exposing midseason oranges, colored and uncolored, to a 5-percent borax solution at various temperatures. Composite of results obtained from 5-minutes' exposure and dipping.

TIME OF APPLICATION

Heretofore, in commercial practice, application of the antiseptic has been delayed until after the fruit receives the coloring treatment, which is commonly from 1½ to 3 days, or longer, after harvest. During this time the fruit is held under conditions of high temperature, high humidity, and under the influence of ethylene gas, providing ideal conditions for the growth of stem-end rot fungi and the development of decay. This suggested the desirability of determining whether application of the borax treatment before coloring

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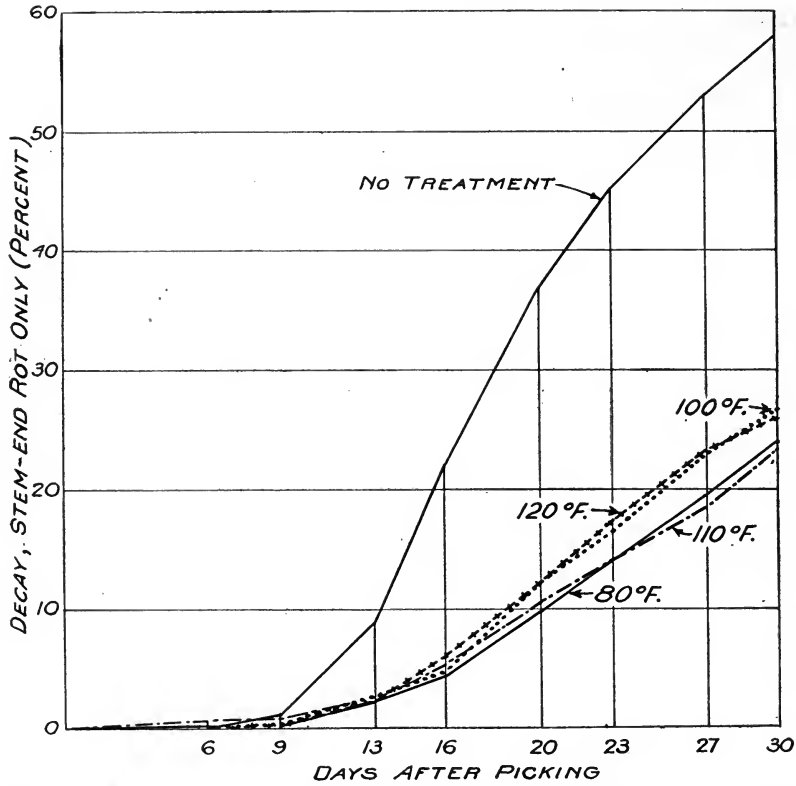

FIGURE 8.—Effect on stem-end rot of exposing midseason oranges, colored and uncolored, to a 5-percent borax solution at various temperatures. Composite of results obtained from 5-minutes' exposure and dipping.

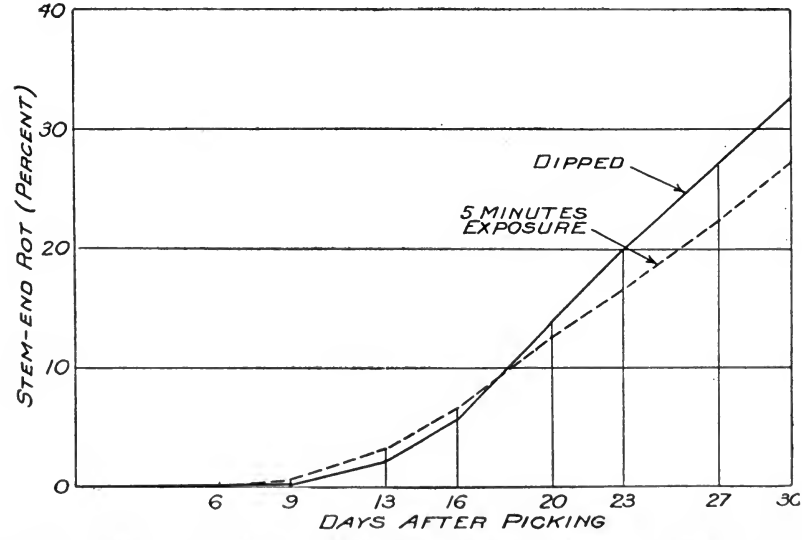

FIGURE 9.—Effect on stem-end rot of exposing midseason oranges, previous to coloring, to a 5-percent borax solution for 5 minutes or momentary dipping. Average results from solutions at temperatures of 80°, 90°, 100°, 110°, and 120° F.

might not be more effective than the usual commercial treatment after coloring.

Accordingly, a rather extensive series of tests was made in the fall and winter of 1931 in which 12 lots of oranges were divided into four parts: (1) Check—no borax treatment, (2) borax treatment given before coloring, (3) borax treatment given after coloring, and (4) borax treatment given both before and after coloring. A total of from 1,400 to 1,600 fruits were used in each treatment. Fruits used in these tests were obtained from 12 or more representative groves which differed in age, variety, and other characteristics and included fruit of advanced maturity. It was found that fruit from young groves kept better than that from old ones, but approximately the same difference in control was noted between the treated and the

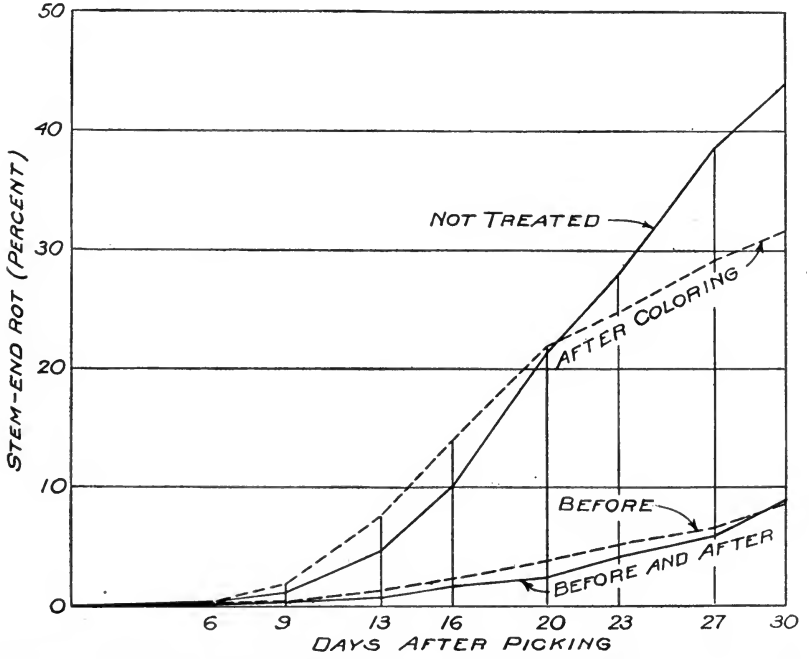

FIGURE 10.—Stem-end rot on midseason oranges treated in a 5-percent borax solution before, after, and both before and after coloring.

checks in fruit from both young and old groves. The results are summarized graphically in figure 10.

Three important points are brought out in figure 10: (1) Stem-end rot was not greatly retarded by an application of borax after coloring, (2) borax applied before coloring retarded stem-end rot to a marked degree, and (3) the double treatment (before and after coloring) was not significantly more effective on this rather mature fruit than a single application before coloring. However, under average commercial conditions where there is considerable variation in the keeping quality of fruit, it is advisable to treat all fruit with borax during the washing operation, regardless of whether an application is made before coloring, because bruises and scratches

opening the way for decay are likely to occur in the handling and washing operations in even the most carefully operated houses.

DELAYED BORAX APPLICATION

Fulton and Bowman [7] have shown that the decay-inhibiting effects of borax are impaired if the application is delayed until several hours after blue mold spores are planted in injured tissues. This, doubtless, accounts for the abnormal development of blue mold rot in fruit that is hauled long distances before treatment with borax, particularly that which is picked while wet or has been rained on after picking.

In winter or in cool foggy weather blue mold is often a problem because of favorable temperature and humidity conditions. During the experimental work, showers, heavy dews, and various other difficulties sometimes caused a delay in the application of borax to experimental lots of fruit until the day after picking. When, in addition, the fruit had to be hauled long distances to the packing house, conditions very favorable for blue mold development resulted and considerable loss from penicillium rots occurred despite the borax treatment which was subsequently given. Doubtless this increase in blue mold rot was due to the delay in the application of borax.

Ordinarily, blue mold is most serious during December and January when the weather is comparatively cool. At this time, during the 1932–33 shipping season, experiments were conducted to determine the comparative effects of immediate treatment with borax and an overnight delay before application. Oranges and grapefruit that had been severely scratched or bruised were dipped into a suspension of blue mold spores and were then given the borax treatment; one portion immediately, and the other following an overnight delay. The conditions thus provided were very comparable to those frequently arising in commercial practice during unfavorable weather, especially when field boxes are overfilled. These injuries were of the kind that could be detected easily on the grading belt. Several hundred fruits were used in these tests. Delayed application of borax reduced blue mold decay to some extent but was not as effective as immediate treatment, and the momentary dip into the antiseptic solution was not so effective as a 5-minute exposure at 110° F. However, in no case was the suppression of decay sufficiently great to be commercially satisfactory, but it is possible that the character of the lesions that became infected may have been responsible in some measure for the ineffectiveness of the antiseptic. These results, therefore, emphasize the importance of relying on careful handling as the most effective means of preventing blue mold rot. They indicate also that if fruit must be harvested or hauled in rainy or foggy weather an application of borax should be given as soon as possible after the fruit is picked or otherwise handled. This antiseptic treatment of carefully handled or even slightly bruised fruit should result in much less decay by blue mold.

In order to determine whether a delay in applying borax is similarly reflected in an increase in stem-end rot decay, tests were

[7] FULTON, H. R., and BOWMAN, J. J. See footnote 5.

made with oranges on three different occasions and with grapefruit twice in the spring of 1933 after warm weather had reduced the hazard of blue mold. The experimental fruit was divided into 4 lots of 230 oranges and 50 grapefruits each. One lot was given a borax bath immediately after picking and was then subjected to the usual coloring treatment; the remaining three lots were placed in a 70° F. holding room. On the following day a second lot was withdrawn from the holding room, treated with borax, and placed in the coloring room. This procedure was repeated on the third and fourth days so that comparisons could be made between immediate treatment and delays of 1, 2, and 3 days before application of the antiseptic. Each lot of fruit was given the same coloring treatment, at the conclusion of which the borax residue was washed off and the fruit was returned to the 70° F. holding room for extended observation. The results of these experiments were not entirely conclusive. However, during such delays as will be shown later, rapid development of stem-end rot usually occurs when the fruit is subjected to the usual coloring treatment. Delaying application of the borax treatment, therefore, cannot be regarded as good practice and should be avoided as much as possible.

BORAX ON UNCOLORED ORANGES

During the course of these experiments with borax on fruit that was subsequently subjected to the coloring treatment, similar fruit was held in the open air for comparison. These check lots were treated with borax in the usual way, but instead of being placed in warm coloring rooms they were stored in an open shed while other lots were receiving the coloring treatment. At the end of the coloring period, the borax residue was washed off from both lots and the fruit was then transferred to a holding room maintained at a temperature of 70° F. In both of the years during which these experiments were conducted the results were consistent in proving the effectiveness of the borax treatment. Figure 11 shows the differences in stem-end rot obtained in 13 lots of untreated and 12 lots of treated early and midseason oranges, and in 9 lots of untreated and 9 of treated Valencia oranges, averaging somewhat more than 100 fruits per lot.

The reduction in decay in the early and midseason oranges was greater than in the Valencia oranges, probably because the early oranges were from younger trees and were somewhat less mature at the time of treatment, hence, less subject to rapid decay. No evidence has been obtained that one variety of orange is more susceptible to stem-end rot than another. A comparison of the results shown in figure 11 with those presented in figure 10 shows that stem-end rot was very markedly increased by the coloring treatment, the maturity of the fruit, and possibly other factors, but that by use of the 5-percent borax solution the loss from stem-end rot even on this fruit was less than on fruit that received neither the borax nor the coloring treatment.

REMOVAL OF BORAX DEPOSITS

The length of time that borax should be allowed to remain on the fruit in order to effect maximum control of decay has an important

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bearing on the commercial usefulness of this antiseptic. A deposit of borax on market fruit is objectionable, therefore it should be washed off before the fruit is packed. To determine the extent to which this removal of borax affects the control of decay, a series of experiments was conducted in 1932, using firm, fully matured midseason oranges. Four tests were made on uncolored fruit of the Pineapple and Ruby Blood varieties of oranges from three different groves, employing more than 400 fruits per treatment. The results indicated that when the borax solution was rinsed off immediately after being applied, as in the ordinary commercial practice, stem-end rot was reduced only slightly below the untreated checks; however, when the borax deposit was left on for 48 hours there was a further

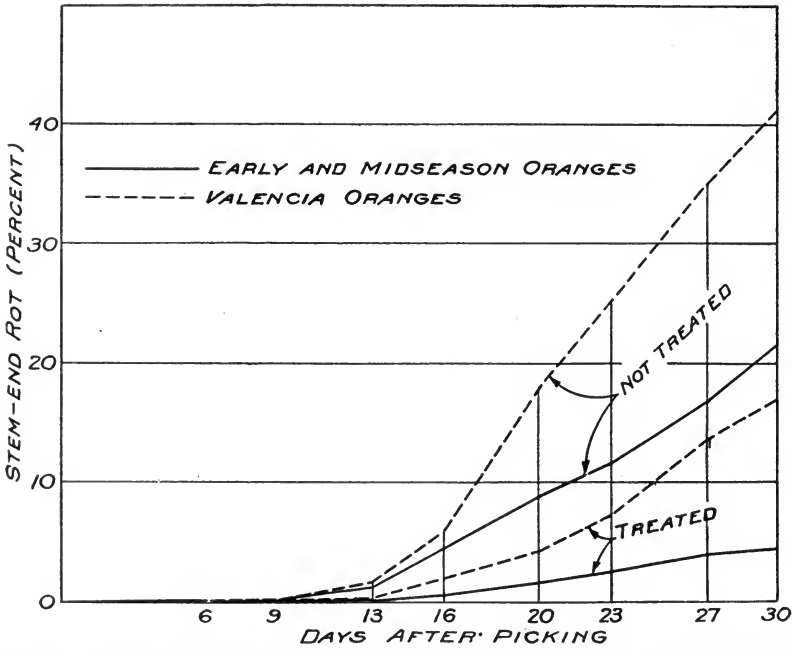

FIGURE 11.—Stem-end rot on uncolored early and midseason and on uncolored Valencia oranges treated with a 5-percent borax solution. Borax residue removed after 72 hours.

reduction, and a still greater reduction when the borax deposit was left on the fruit throughout the holding period, the maximum reduction occurring during the latter half of the holding period (fig. 12). Had this fruit been less mature, there undoubtedly would have been a greater difference in decay between the treated and the untreated lots. (See fig. 11 for comparison.)

Another test was conducted subsequently in which similar sized samples were gathered from seedling orange groves when the fruit was almost dead ripe and hence much weaker and more subject to rapid spoilage. It was again found that when the borax was rinsed off immediately after being applied it had little or no effect on stem-end rot, whereas that left on throughout the holding period was fairly effective, although not to the same extent as in the experiments

illustrated in figure 12, which included less senile fruit. Blue mold was quite effectively controlled in both tests.

The experiments were continued on Valencia oranges and grapefruit during March and April 1933, and on budded oranges in November 1933. In these tests the fruit was treated with an 8-percent borax solution and washed in clean water after intervals of 5 minutes, 1, 2, 4, 6, and 8 hours. Quadruplicate lots consisting of approximately 300 fruits each were used. The results, while not as clear-cut as in the earlier tests on more susceptible fruit, again indicated that to be most effective in rot control the borax should not be washed from the fruit until after 6 or 8 hours.

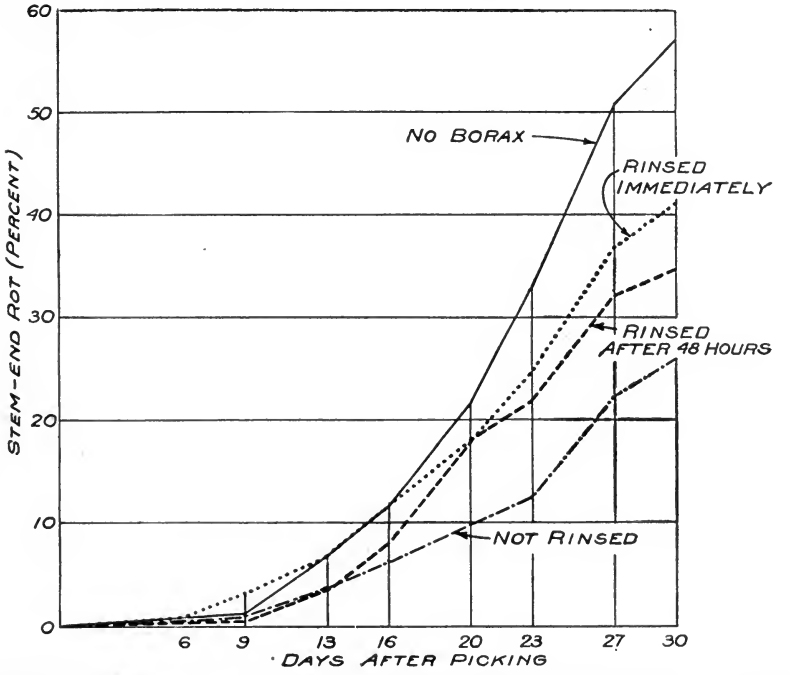

FIGURE 12.—Effect on stem-end rot of allowing borax residue to remain on uncolored midseason oranges for various lengths of time.

No definite experimental evidence was obtained as to whether the antiseptic action of the borax continued after the treating solution had dried on the fruit; however, it is believed that the effects were obtained chiefly while the fruit was still wet with the antiseptic solution.

INFLUENCE OF MATURITY ON EFFICACY OF BORAX

It is well known that citrus fruit can be stored on the tree for several weeks after it reaches maturity and that this practice is followed in all producing districts, harvesting operations being determined to a large extent by the market demand.

When oranges first reach maturity ordinarily they are not especially subject to rapid spoilage from either stem-end rot, blue mold, or green mold, but as they become more mature the rate of decay

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subsequent to packing increases rapidly. Dead-ripe fruit is especially susceptible to stem-end rot and can be marketed in a sound condition only with extreme difficulty. Experiments were therefore undertaken to determine the effect of the borax treatment on the keeping quality of such fruit. These tests were made in the spring of 1932 and again in 1933, using fruit so ripe that the slightest pressure would pull it from its stem. The first season's records were not made with respect to the retention of stems, but in 1933 the fruit was divided into two classes: (1) With stems adhering, and (2) without stems.

In both seasons the fruit was given the customary 5-percent borax treatment, but the 1933 fruit was also subjected to the ethylene coloring treatment for 50 hours and then stored. Very little difference was noted in the rate of decay between the treated and the untreated fruits, or between those without stems as compared with those with stems attached. These results indicated that the causal organisms had penetrated too deeply into the tissues to be reached by the antiseptic at the time of treatment.

INFLUENCE OF BORAX ON COLOR DEVELOPMENT AND LOSS OF WEIGHT

Throughout these experiments close observations were made on differences in the rate of coloring in fruit treated with borax as compared with the untreated lots in both the noncolored (not gassed) checks as well as in fruit subjected to ethylene to accelerate the disappearance of the green pigment.

With oranges, grapefruit, tangerines, Satsumas, and other common citrus species, no evidence was found to indicate that a deposit of borax tends to retard color development, either when forced with ethylene or allowed to proceed at the normal rate under atmospheric conditions. Similar observations have been made on fruit handled in commercial operations. It is evident that the rate of coloring is affected chiefly by such factors as temperature, humidity, and chemical constituents of the atmosphere rather than by the presence of borax on the fruit.

Several hundred carloads of citrus fruits, mostly oranges, were commercially treated with borax before coloring during the season of 1932–33, and a much larger number during the season of 1933–34. The results in general indicated that the borax deposit did not retard the rate of coloring nor did it in any manner make the fruit more difficult to clean.

Records were secured on the loss of weight of Valencia oranges treated with borax and colored, as compared with corresponding lots treated with plain water and colored. The results showed that the fruit treated with borax lost weight at essentially the same rate as did the untreated checks, proving that the rate of wilting is not affected by the treatment.

Quantitative chemical determinations were made for borax residue on fruit treated with solutions of different concentrations of borax in a 110° F. bath, both as a momentary dip and as a 5-minute immersion, using fruit at 50°, 72°, and 83° and dried in still air at these temperatures. These tests showed a general relationship between the concentration of the bath and borax deposited, also that there was a slightly less deposit from a momentary dip than

from a 5-minute immersion (table 1). Fruit russeted by rust mites retained practically no more borax than bright fruit.

Similar tests made earlier in the season with dirtier fruit indicated the same general trend, but such fruit retained a greater amount of borax.

COMMERCIAL OPERATION

Because of the results of the experimental work reported above, during the 1932–33 season several packing houses installed equipment for applying borax to fruit before placing it in the coloring rooms. A number of others utilized the regular washing equipment to apply the borax treatment before coloring by shunting the fruit into field boxes from the second or "borax" tank of the usual packing-house equipment and then placing it in the coloring rooms.

TABLE 1.—*Borax residue on Valencia oranges after momentary and 5-minute treatments and drying in still air at different temperatures with borax solution at different concentrations, 1934*

GRAMS OF BORAX PER 100 POUNDS OF FRUIT

Date	Borax	50° F.		72° F.		83° F.	
		Momentary	5 minutes	Momentary	5 minutes	Momentary	5 minutes
	Percent						
May 22	3.15	2.776	2.761	2.301	2.346	1.914	2.445
May 25	3.15	2.933	3.913	2.600	3.077	2.072	3.059
Average		2.854	3.337	2.450	2.711	1.993	2.752
May 22	6.59	3.260	5.046	4.385	4.489	4.494	5.309
May 25	6.59	4.441	6.116	4.280	5.565	5.047	6.151
Average		3.850	5.581	4.332	5.027	4.770	5.730
May 22	13.21	9.172	11.584	9.581	10.394	10.764	10.360
May 25	13.21	13.950	12.900	9.960	12.890	13.290	14.440
Average		11.561	12.242	9.770	11.642	12.027	12.400

GRAMS OF BORAX PER 1,000 CM² SURFACE

May 22	3.15	0.089	0.087	0.072	0.074	0.062	0.076
May 25	3.15	.092	.126	.082	.094	.087	.098
Average		.0905	.1065	.0770	.08400	.07450	.0870
May 22	6.59	.100	.161	.148	.142	.138	.163
May 25	6.59	.145	.181	.134	.177	.160	.192
Average		.1225	.1710	.1410	.1595	.1490	.1775
May 22	13.21	.291	.365	.292	.331	.347	.345
May 25	13.21	.467	.416	.325	.408	.408	.433
Average		.3790	.3905	.3085	.3695	.3775	.3890

In the first commercial attempts to use the borax treatment before coloring, ordinary citrus lug boxes filled with fruit were dipped into the antiseptic solution just as they were received at the packing house (fig. 13). Although this was a somewhat laborious method of applying borax, it was effective. Another procedure, developed shortly afterward, was to use a small vat, movable on casters and

having heating facilities. This was equipped with a hand-operated carriage that submerged the fruit and the container and then elevated them to a roller conveyer on which the treated boxes were moved away (fig. 14). Use of the roller conveyer allowed the greater part of the excess borax solution to drip back into the tank.

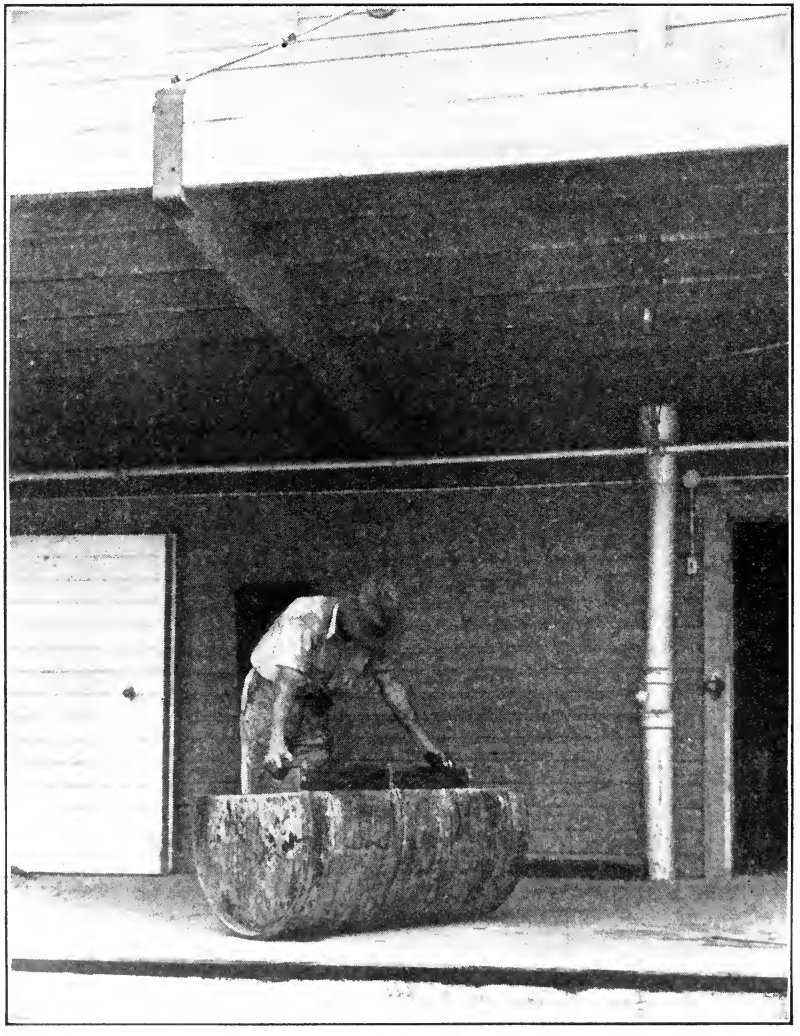

FIGURE 13.—Dipping oranges in ordinary citrus lug boxes into borax solution.

This proved to be a rapid and inexpensive method of applying borax, but it was rather sloppy and required much hand labor.

This method was also open to the criticism that the field boxes or lugs became wet. This is objectionable, particularly when the coloring rooms have inadequate provision for evaporating excess moisture. However, there is an offsetting advantage in not having to empty the crates and refill them, thereby reducing the chances

of bruising and injuring the fruit, which is of special importance early in the season when the oil cells are easily ruptured.

A more recent development in the treating method consists of the use of a few transverse scrubbing brushes or roller conveyers, a small soaking tank with heating equipment and with a conveyer belt on which fruit can be graded, as shown in figure 15. After the fruit is dumped, the empty field boxes are carried by gravity conveyers to the far end of the loading belt where they are filled with treated fruit and trucked to the coloring rooms. This method

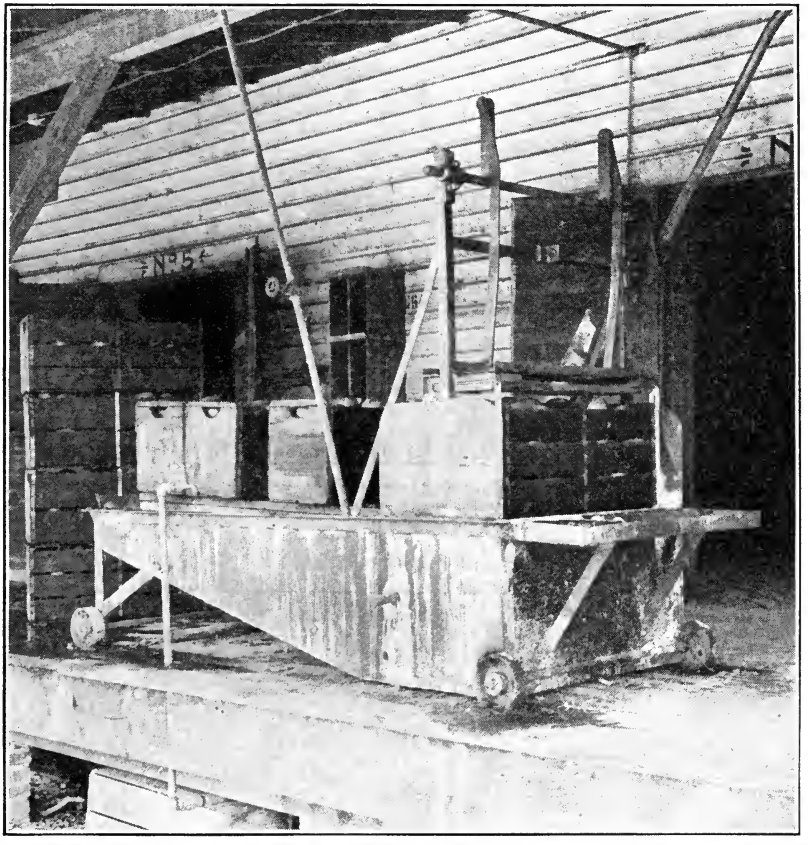

FIGURE 14.—A movable borax dipping tank with hand-operated carriage. The fruit in ordinary lug boxes is first submerged and then elevated to a roller conveyer.

of applying borax has a number of advantages, chief among which is the fact that since the boxes are not wetted the fruit can be dried more quickly. This method is favored by many commercial packers. It is also more economical in the consumption of borax, but, because of emptying and refilling each box, mechanical injury of the fruit is more likely to occur, although in the usual commercial operations very little injury is actually experienced. The treating equipment is often placed on small wheels enabling it to be moved wherever it may be needed, and it is used with a specially padded hopper for catching the treated fruit with the least risk of bruising (fig. 16).

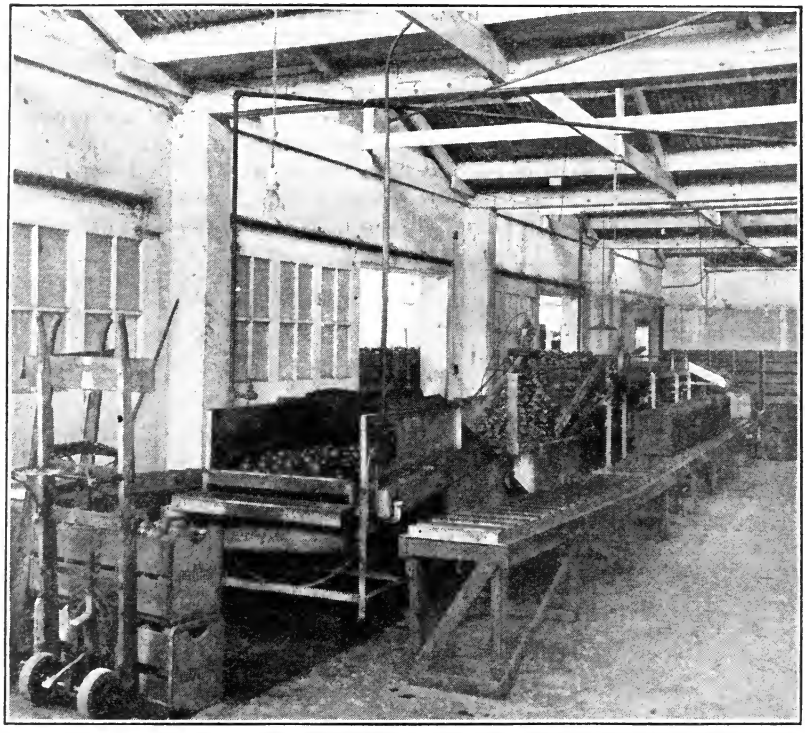

FIGURE 15.—Improved borax-treating apparatus comprising a small soaking tank with heating equipment, some transverse scrubbing brushes or roller conveyors, and a belt upon which the fruit can be graded.

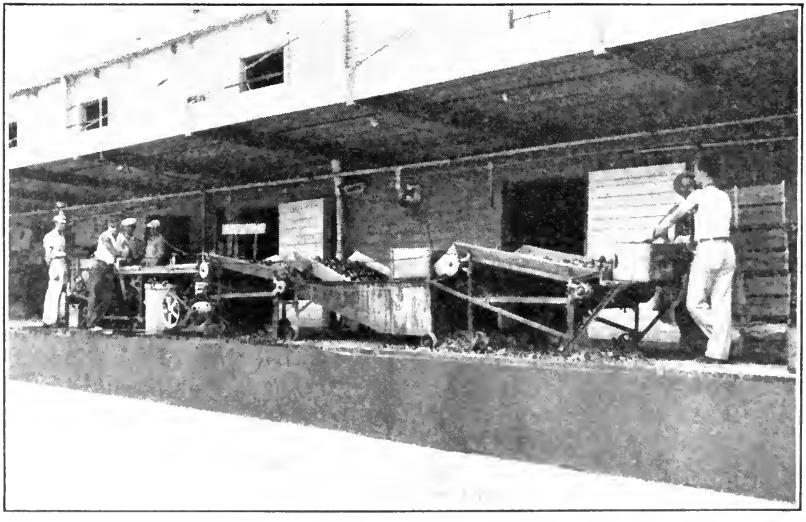

FIGURE 16.—Borax-treating apparatus mounted on wheels to permit moving wherever desired along receiving platform. This illustration also shows the use of a specially constructed hopper to receive the treated fruit with the least risk of bruising.

The most recent commercial developments or adaptations of the method are modifications of those illustrated in figures 15 and 16, the essential difference being in the use of longer borax tanks to prolong the time of treatment. Some of the newer tanks are large enough to permit a normal flow of fruit to remain in the bath 10 or more minutes, which is considered especially desirable in cold weather not only because it permits more borax to remain in solution longer on the fruit, but the preheating also shortens the time necessary to raise the fruit to the temperature subsequently required for coloring.

While the methods of applying borax, as described, have certain advantages, it is believed that a regular washing procedure, including the use of a soaking tank, scrubbers, and a borax tank, might be desirable in small packing houses when the fruit is received from the orchard, especially during cool weather. It would be necessary, however, to have both tanks equipped with steam pipes so that cold fruit could be warmed up sufficiently to retain an effective amount of borax in solution. It is necessary to heat the borax solution during the greater part of the shipping season in order to prevent the temperature of the bath from falling below the saturation temperature of the desired concentration. In warm weather, however, heat may be needed only during the early morning.

It has been found that in cool weather the fruit often needs to be warmed before treatment to insure the maximum effect from the borax solution. The most economical and effective method of warming the fruit is a problem that varies from one packing house to another and requires individual solution. In some houses it has been found practical to utilize the coloring rooms with their steam-heating and air-circulating equipment. This, however, involves extra handling and added costs. In many packing houses it is found to be most practical to rely on the use of the long borax tanks to heat the fruit effectively for the treatment. It is possible also that sodium metaborate may be used as a substitute for borax during cold weather on account of its greater solubility.

TESTS UNDER COMMERCIAL CONDITIONS

Much of the experimental work conducted at the laboratory was repeated under commercial conditions. In midwinter fully mature oranges in need of the coloring treatment were selected from four groves that were notorious for producing fruit of unusually poor keeping quality. These lots were divided into two groups—one was dipped with the container into a warm 5-percent borax solution and the other was untreated. Both lots were then colored for 40 hours in the commercial way, together with a room full of other fruit. At the end of the coloring period composite samples from each lot totaling more than 400 fruits for each group were transferred to the holding room for observation. The decay record of these lots is presented in figure 17.

From these results it is apparent that the borax treatment controlled decay effectively for about 3 weeks even at a temperature of 70° F., whereas the loss in untreated fruit was very severe, being as great at the end of about 10 days as it was in the treated lots after 21 days.

In connection with observations on commercial operations, it has been noted repeatedly that on weak fruit treated with borax a brownish discoloration often develops on a small percentage of the fruit in the stem area after holding for about 2 or 3 weeks. Occasionally a rot caused by *Colletotrichum* sp. developed in these areas, but it was readily distinguishable from that caused by *Phomopsis* and *Diplodia*. Susceptibility to such injury from the borax treatment appears to vary considerably with the particular crop involved and

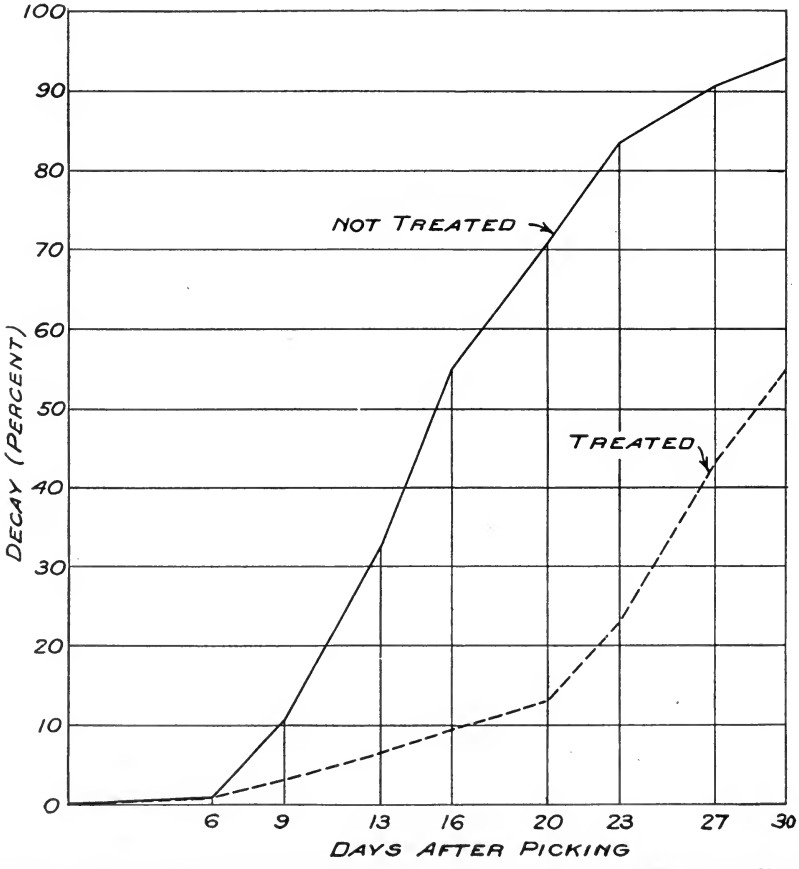

FIGURE 17.—Decay of midseason oranges, of poor keeping quality, as affected by dipping in a warm 5-percent borax solution before coloring under commercial conditions.

to increase when the time required for the fruit to dry is excessively long. Ordinarily, it has been of little or no commercial consequence.

The cost of the borax treatment varies with the facilities available in the different packing houses, but ordinarily it is from one-half to two-thirds of a cent per 100 pounds of fruit.

THE COLD WEATHER FACTOR

During 1 or 2 cold spells the 5-percent borax treatment, as used commercially, before coloring, failed to give protection against decay. An investigation into the trouble indicated two possible con-

tributing factors: The use of too much live steam in the coloring treatment, and the low temperature of the fruit at the time of the borax treatment. A too liberal use of steam at the beginning of the coloring period tends to wash off the borax from fruit in the lower and cooler boxes. When the fruit temperature is below the saturation point of the weakest effective concentration of the borax solution the fruit does not retain in solution a sufficient amount of borax to be properly protected against rot fungi. Unless the borax tank is equipped with adequate heating facilities, the solution may be-

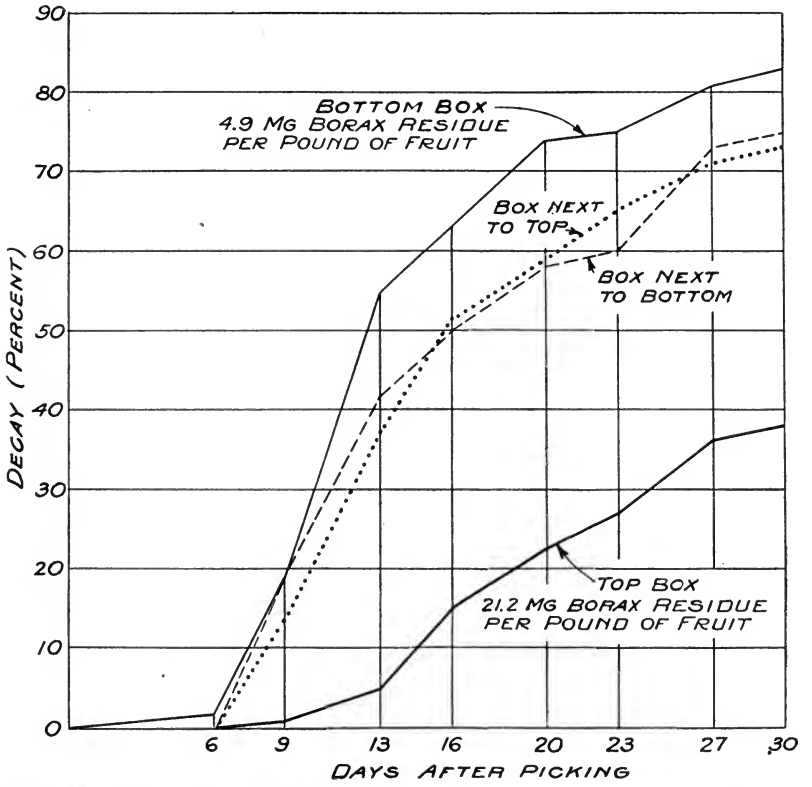

FIGURE 18.—Decay in different layers of midseason oranges as related to removal of borax by excessive steam in the coloring room.

come chilled by the passage of cold fruit, thereby resulting in lowering the concentration of borax in solution.

Special tests were conducted to prove these points and it was found that the liberal use of steam during the warming up portion of the coloring period resulted in the washing off of the borax from the cooler fruit in the lower part of the stacks. Samples of fruit to be held for extended observation and for chemical analyses were taken and the results are summarized in figure 18.

It will be noted that from two to four times as much borax was found on the fruit from the top boxes as on that from the bottom boxes. This doubtless had an important influence on the keeping

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quality of the fruit in the lower boxes. In all of these instances the fruit was wet from the borax treatment and was in wet boxes when placed in the coloring rooms. Complications immediately arose in the condensation of water on the fruit in the lower boxes. Samples for a storage test were taken from the dumping belt during the regular packing operation subsequent to the coloring treatment. The results showed that the fruit in the lower boxes received less protection than that in the top boxes, because of the washing off of the borax as noted above. The protection noted was, in general, proportional to the borax residue recovered.

When the commercial use of borax before coloring was first attempted the dipping vats were not equipped with facilities for keeping the bath warm. Satisfactory results were secured until the onset of cold weather when almost without exception shippers experienced increased losses from decay, indicating that cold weather had introduced a new factor in the problem.

A special series of tests were then made under commercial conditions to determine the influence of the fruit temperature at the time of treatment in the effectiveness of borax as an antiseptic. At the same time, and with samples of fruit from the same grove, tests were made to determine the influence of wet boxes on the subsequent keeping quality of borax-treated fruit. The fruit used was taken from four groves that had consistently produced fruit of poor carrying quality. The lots used averaged 275 fruits for each treatment. All of the experimental lots were colored in rooms filled with commercial fruit treated with borax by dipping the fruit and boxes. Figure 19 gives the summarized results of these tests made in December 1932 with midseason oranges.

It will be noted that cold fruit was not adequately protected by the borax treatment, even prolonged exposure in the warm, nonagitated borax bath being only partially effective. In the experiments on the influence of wet boxes it was found that the fruit colored in dry boxes kept better than that held in wet boxes during the coloring period. Without exception, each lot transferred to dry boxes after being treated with borax decayed less rapidly than the corresponding lot left in wet boxes.

Unless the borax solution is heated it soon reaches the average temperature of the fruit being dipped. Thus, in cool weather, difficulty is encountered in maintaining the proper concentration of borax unless special steps are taken to keep the borax bath warm, because of the low solubility of borax in cold water. Likewise, when cold fruit was dipped it is probable that the film of borax solution adhering to the fruit lost a large part of its borax through crystallization and subsequent washing off of a portion of these crystals while the fruit was dripping. This may be of special importance whenever the borax solution is used at less than maximum effective concentration.

The accompanying chart (fig. 20) can be used as a convenient guide in maintaining any desired concentration of borax. To use this chart, all the equipment that is needed is a thermometer and a Brix hydrometer, such as is used in making the customary maturity tests on citrus fruit.

In this chart, temperature is indicated by oblique lines, gravity (Brix) by perpendicular lines, and percent of borax by horizontal lines. Its use may be illustrated by the following example:

If the temperature of the bath (indicated by the oblique lines) is 90° F. and the Brix reading (shown as perpendicular lines) is 6.5 the concentration can be determined by following the oblique temperature line down until it cuts the perpendicular line, representing the Brix reading, then extending that point in a horizontal direction to the left of the chart, the amount of borax in solution is found to be approximately 6 percent. Usually, a borax solution of the desired concentration should be prepared in a special container such as a barrel or a large garbage can and then added to the dipping tank as needed. It will be noted that a Brix reading of 5 for a tank temperature of 70° indicates approximately a 4-percent borax solution, and the same Brix reading for a temperature of 100° indicates a 5-percent solution.

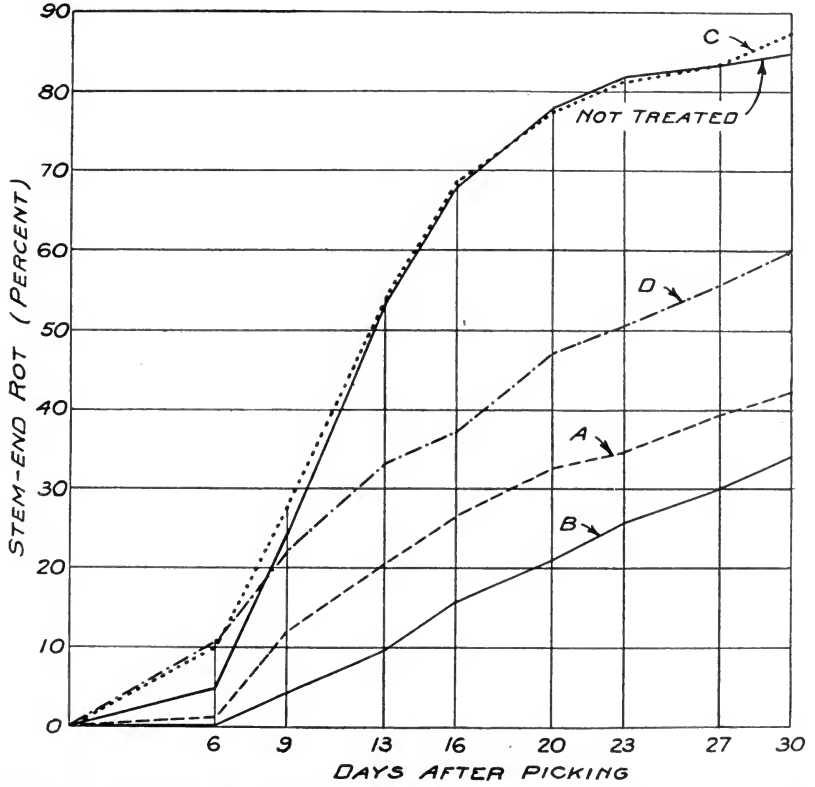

FIGURE 19.—Stem-end rot on midseason oranges as affected by temperature of fruit when exposed to a warm 5-percent borax solution before coloring and by various methods of handling: *A*, Fruit 70° F., dipped, left in wet boxes; *B*, fruit 70° F., dipped, transferred to dry boxes; *C*, fruit 50°–60° F., dipped, left in wet boxes; *D*, fruit 50°–60° F., 5-minute exposure, left in wet boxes.

Because of low solubility of borax it is not feasible to attempt to make a concentrated solution for subsequent dilution. However, concentrations up to 10 or 12 percent can be prepared with little difficulty by introducing live steam into the dissolving vessel, or by applying bottom heat. In the latter case, the solution should be stirred while heating.

For the solution of the problem of successfully treating citrus fruit with borax in cold weather, the following suggestions are

offered: (1) Use a longer tank in order that the outer rind of the fruit may have an opportunity to warm a little while passing through the borax solution. (2) Pass the fruit through the soaking tank and the borax tank as is the usual practice in washing fruit, and thence direct to dry field boxes. In such cases both tanks should be equipped with heating units. During the 1933–34 season commercial experience indicated that such equipment (fig. 15) was adequate during ordinary winter weather without the necessity of preheating the fruit. (3) Momentary dipping of the cold fruit in a 10- or 12-percent hot borax solution has given satisfactory results in some instances in commercial houses. Undoubtedly adequate amount of borax adhered to the fruit despite the immediate

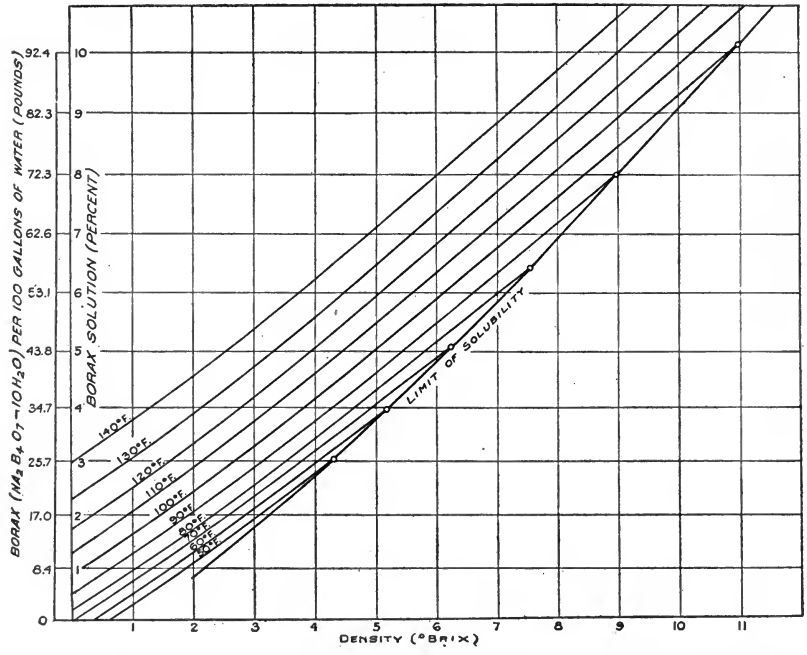

FIGURE 20.—Density of borax solution at different temperatures. One hundred gallons of water at 80° F. = 832 pounds. One cubic foot of water = 7.48 gallons.

crystallization which occurred on its surface, provided the fruit was subsequently warmed in an atmosphere almost saturated with moisture. This method has been used to only a limited extent and its effectiveness has not been fully established. (4) Warm the fruit for a few hours in one of the coloring rooms where the temperature can be raised quickly and can be controlled through provision of adequate means for circulating the air. This prewarming would also serve to shorten considerably the time necessary to bring the fruit to coloring temperatures, and would thereby shorten the time required for coloring. Rind temperatures need not be raised much above the saturation temperature of the borax solution used. (See fig. 20.)

The rate at which fruit can be warmed up in this manner by use of live steam and adequate equipment for air circulation is shown

in figure 21, presenting the results of experiments conducted at Winter Haven, Fla.

From these results it is apparent that the temperature at or near the center of the fruit was raised about 30° in 5 hours in a car lot of fruit using equipment now generally used in coloring operations.

DRYING AFTER BORAX TREATMENT

When the wet borax-treated fruit was handled in dry boxes, little or no difficulty was encountered in drying the fruit in a reasonable time, that is 6 to 8 hours, but when both the fruit and the boxes were wet, especially in damp weather, and the coloring rooms were only partially filled, thereby reducing the amount of air that passed through the filled boxes, the rate of drying was considerably retarded. At such times, as much as 40 hours was required to dry the fruit in the lower part of the stacks. Under commercial conditions this usually resulted in a retarded rate of coloring in these lower boxes. At times, also, the fruit took up so much moisture that some splitting occurred in weak fruit and there was an additional loss in the impaired efficiency in decay control. In warm dry weather and with rooms equipped with large blowers, no trouble is ordinarily experienced in drying fruit, even when it is handled in wet boxes.

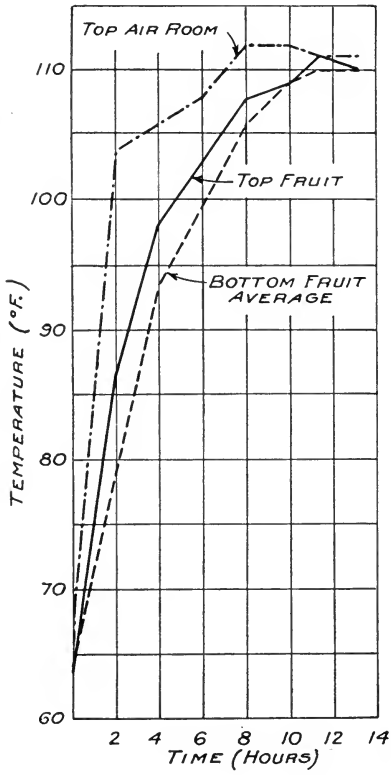

FIGURE 21.—Rate of heating carload lots of grapefruit with live steam previous to coloring.

If coloring rooms are not equipped with blowers of sufficient capacity or if from any cause the air circulation is deficient, it is better to allow the borax-treated fruit and wet boxes to stand for a few hours where natural air currents can remove as much of the excess moisture as possible before transferring to the coloring rooms. If the boxes are not wet, the fruit usually dries quickly enough even in rooms with poor circulation. Under the former conditions it is advisable wherever possible to use dry heat or heat from a steam radiator instead of live steam in heating the fruit for coloring.

SUMMARY

A borax bath given to citrus fruit immediately upon arrival at the packing house was found to retard decay caused by the common stem-end rot and blue mold organisms. Delayed treatments were not as effective.

The borax treatment was found to be effective on fruit needing the coloring treatment as well as on that which was fully colored when harvested.

The antiseptic treatment was much more effective on firm fruit than on over-ripe fruit ready to drop from the tree.

For best results it was found that the concentration of borax should not be less than 8 percent. Whenever possible the wet fruit should be dried slowly and the borax residue should be left on the fruit for several hours.

In cold weather it is desirable to raise the temperature of the rind of the fruit to about 90° F. before giving the borax treatment, in order to retain the maximum effective amount of borax in solution. This may be accomplished by warming the fruit in coloring rooms or by passing it slowly through long tanks with heated borax solution.

In well-organized packing houses the cost of this treatment has not exceeded one-half to two-thirds of a cent per 100 pounds of fruit.

The value of the treatment is reflected in a reduction of decay while the fruit is in transit and in improved keeping quality after the fruit arrives at the market and enters the hands of the retailer and the consumer. Its value is especially apparent when fruit is held on the market for several days, particularly in warm weather.

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BOLLWEEVIL CONTROL WITH CALCIUM ARSENATE ON FIELD PLOTS IN MADISON PARISH, LA., FROM 1920 TO 1934[1]

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INTRODUCTION

From 1920 to 1934, inclusive, a study was made of the effectiveness of calcium arsenate dusting for control of the bollweevil (*Anthonomus grandis* Boh.) under the wide range of conditions prevailing in Madison Parish, La., during this period. Madison Parish borders the Mississippi River in the Delta section of northeastern Louisiana. Here conditions are favorable for the bollweevil, and the damage caused over a series of years is about as great as anywhere in the Cotton Belt. There are large areas of heavy timber, with copious growths of Spanish moss which provide good hibernation shelter, temperatures that are neither extremely high nor extremely low, and abundant rainfall. The soil is fertile, the growing season rather long, and good yields of cotton are normally produced when it is protected from weevil damage.

Most of the tests were conducted within a 14-mile radius of Tallulah. Their purpose was to determine the influence of winter temperatures, the degree of weevil infestation, and the rainfall during the season when most of the squares are produced (June 21 to Aug. 19) on the effectiveness of the calcium arsenate treatments. These

[1] The tests prior to Jan. 27, 1931, were conducted under the direction of B. R. Coad, and since that date under the direction of R. C. Gaines. The field work was performed by the author, assisted by A. Thomae, A. J. Chapman, W. A. Stevenson, F. F. Bondy, C. F. Rainwater, G. L. Garrison, and a number of temporary assistants.

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factors were measured by the square infestation, the number of applications of dust used for weevil control, and the increase in yields of seed cotton. The objectives were, in other words, to test the use of calcium arsenate for weevil control over a series of years and to obtain an index of the damage caused and the gains to be expected from control. In 1920, 1927, and 1928, however, instead of these regular tests, the following special tests were conducted: In 1920 the relative effectiveness of control on early, intermediate, and late weevil infestation was studied. In 1927 the greater part of Madison Parish was flooded as a result of a crevasse in the Mississippi River levee on May 3, and 3 series of tests were conducted—2 series, 1 in the eastern and 1 in the western portion of the parish, on late cotton planted after the flood waters had receded, and the third in the eastern portion of the parish on land that had not been flooded. In 1928 a comparison was made of the effectiveness of the treatments on cotton on land that had and had not been planted to cotton the previous year. In 1932 special tests were made in addition to the regular tests, to determine the effectiveness of treatments applied late in the season, when field migration of weevils was in progress and the infestation was very heavy.

In the regular tests calcium arsenate was used according to the standard method; that is, dusting was begun when approximately 10 percent of the squares were punctured and repeated at 4- or 5-day intervals as long as was necessary to keep the weevils under control. Most of the bolls are produced during a period of approximately 2 months, and it is during this heavy fruiting period that protection from weevils is most essential. The cotton plant always produces many more squares than can be matured as bolls, and under normal conditions about 60 percent of the squares are shed. The shedding of weevil-punctured squares up to a certain point is therefore not injurious and does not prevent the production of a full crop of cotton.

Some of the weevils are not killed until several days after the treatment, and in the meantime weevils that eventually die may continue to puncture squares. The bollweevil is never completely controlled by dusting with calcium arsenate, and some weevils can always be found in a successfully dusted field. The high square infestations recorded in the treated plots late in the season are due to the very few squares that were present at the time and the general dispersal of weevils late in the summer.

It is sometimes difficult to determine when dusting should be discontinued. Usually it does not pay to protect the squares after the cotton has practically stopped fruiting and there is a general dispersal of weevils, but it is frequently profitable to make additional applications if there is a crop of young bolls still subject to damage. Under favorable conditions sufficient control may be obtained to make a good yield after the square infestation has become very high and fall migration is in progress, as shown by the late-season tests in 1932.

It should be emphasized that growers dusting their entire fields obtain better results with fewer applications of calcium arsenate than were obtained by dusting small areas surrounded by large areas of untreated cotton such as were used in these tests. Bollweevils invariably moved into the treated plots from the surrounding untreated areas and control by calcium arsenate dusting was put to a severe test.

PROCEDURE

SELECTION OF TEST PLOTS

Each year a survey was made in Madison Parish to find cotton fields that could be divided into plots that would produce, as nearly as could be predetermined, the same quantity of cotton per acre without the calcium arsenate treatment. Two plots, one treated with calcium arsenate and the other untreated, constituted a test, or cut. From 4 to 17 tests were made each year. For each test it was essential to choose plots that had been planted on the same date with the same variety of cotton in soil of uniform fertility and, where fertilizer was used, that had received the same quantity and kind per acre. It was necessary that the cotton plants be of good color, of average size and stand, and for the same test that the initial weevil infestation be as nearly uniform as possible. Fields near hibernation quarters were usually selected as being most likely to become heavily infested. For all the tests cotton was chosen on which no control had been attempted during the current season.

In 10 years of the 15-year period 2-plot tests were made especially for this study, but in 1924, 1925, 1932, 1933, and 1934 the calcium arsenate-treated and the untreated plots of 3-plot tests conducted in connection with other experiments were used in order that there might be a complete series of records.

In each test the treated plot and the untreated plot were parallel to each other. Each plot was usually 300 feet long and the rows were approximately 4 feet wide. From 1920 to 1932 a plot consisted of 30 or more rows, and in 1933 and 1934 of from 18 to 26 rows, with 20 rows in most plots. In a 30-row plot this gave a rectangle about 300 by 120 feet, or 0.8 acre, and in a 20-row plot an area approximately 300 by 80 feet, or 0.55 acre. When the plots were laid off, 25 or more feet at each end of each row was discarded, because the stands are more likely to be poor there. The area treated, however, included the row ends and usually covered from about 0.6 to 1.5 acres. Just before picking, additional buffer areas consisting of five or more rows on each side of the plot were also discarded, because in the treated plots they were most liable to injury by weevils migrating from adjoining untreated cotton, and in the untreated plots, being nearest the treated plots, they undoubtedly received some benefit from the drift of the calcium arsenate. The picking area, from 1920 to 1930, inclusive, consisted usually of 20 rows, covering approximately half an acre, and from 1931 to 1934, inclusive, of from 8 to 16 rows, with 10 rows in most plots, or an area ranging from about 0.2 to 0.3 acre.

KINDS OF RECORDS MADE

So many factors influence the yield of cotton and the damage caused by weevils, especially in plot work, that records were kept of the condition of the plants and weevils throughout the season to furnish as nearly complete a comparison as possible of the treated and the untreated plots. Beginning with 1924 and continuing through 1932, the plants were counted in 20 rows in the center of each plot, but in 1933 and 1934 the plants were counted in the area selected for

picking; from these counts the number of plants per acre was determined. The average height of the plants was calculated, usually at biweekly intervals, from measurements of from 300 to 600 plants per plot.

The number of overwintering weevils present, or the initial spring population, was determined at weekly intervals during May and June of each year except 1927 by counting the weevils on 200 plants near the center and 200 near the ends of each plot. These counts were supplemented with additional counts made on representative fields in this locality in order to obtain a fair indication of the weevil population in the field for this period. From these data the number of plants per weevil was calculated. These population records were made before the plants were large enough to produce squares, and served as an index of weevil emergence from hibernation and migration to the fields in the spring, as well as of the distribution of the weevils in the plots before square infestation was possible.

Square-infestation counts to determine the number infested with weevils were started as soon as the plants averaged 4 or 5 squares each and were continued throughout the season, usually at weekly intervals, as long as the plants continued to have this number of squares. Examinations were made of 200 squares near each of the three points selected for plant-count records, or a total of 600 squares in each plot. At each point every square large enough to be punctured by bollweevils was examined on every plant in several rows until 200 squares had been examined. From these figures the percentages of square infestation were computed. These records are an index of the progressive seasonal weevil infestation.

Bloom-count records were made by counting the red and the white blooms in 10 rows in the center of each plot and calculating the number of blooms per acre. These counts were made as often as possible, usually once or twice a week, from the time blooming became general until it practically ceased in the middle or latter part of August.

Form-count records were made in each year, except 1934, by counting and recording separately the number of squares, blooms, and bolls on 50 or 100 plants at each of the three points in the plot selected for the square-infestation counts. These counts were started as soon as squaring became general and repeated, usually at biweekly intervals, until the middle or latter part of July.

Boll counts were made in the same manner by counting all the bolls on 100 plants at each of the three points. They were started about 2 weeks after the form counts had been discontinued, and usually from 2 to 5 counts were made in each plot during August, when the cotton plants were practically mature and natural shedding of young bolls had taken place.

The yields of seed cotton were obtained by picking the cotton from a portion of the plot as described under Selection of Test Plots, and computing to an acre basis.

The records of calcium arsenate applications will be discussed under the next heading.

Temperature and rainfall records were kept throughout the 15-year period.

Because of the multiplicity of data involved and the difficulties of summarizing, only the records of the calcium arsenate applications,

the square infestation, the yields of seed cotton, the minimum winter temperatures, the average plants per weevil in May and June, the rainfall, and the number of days with 0.3 inch or more rainfall from June 21 to August 19 are summarized in this bulletin. The other records were often of assistance in interpreting any unusual results and were of great value in determining whether the different plots of a test were uniform before treatment and the effect of treatment on fruiting and plant growth, as well as in determining when the crop was "made" and when applications of calcium arsenate were no longer needed.

APPLICATION OF CALCIUM ARSENATE

All the calcium arsenate was of commercial manufacture and, although several brands were used during the 15-year period, no attempt was made in these tests to compare the effectiveness of the material from different manufacturers.

Whenever possible, the plants were dusted with calcium arsenate while they were wet with dew and when the atmosphere was calm. Most of the applications were started soon after daybreak and were completed by 7:30 a. m. In the few instances in which they were made late in the afternoon the air was quiet.

All applications were made with hand dust guns, under the direct supervision of the writer or one of his assistants. Usually 3 or 4 dust guns, regulated as nearly as possible to the same rate of discharge, were used on each plot. The dust guns were weighed after filling and again after each plot had been dusted, and the quantity of calcium arsenate used was computed to an acre basis. An effort was made to put on just enough dust to cover the plants thoroughly; therefore, the quantities used per acre varied according to the size of the plants.

In most of the tests the standard practice of beginning treatments when the square infestation has reached 10 percent was followed, but during 1921, 1922, 1923, 1926, 1929, 1930, and 1931 on many of the plots dusting was started before this and continued later in the season. In the special tests conducted in 1932 to determine the feasibility of weevil control late in the season, when the infestation was very high and field migration was in progress, the applications were not started until the square infestations had reached almost 90 percent.

When a fairly heavy rain fell within 24 hours after an application, this application was considered ineffective and was repeated the next day or as soon thereafter as possible. Applications were repeated at 4- or 5-day intervals when necessary for control until the crop was set and matured, after which there was little probability of weevil injury. In practically all tests at least one application was made primarily for the protection of young bolls. The actual date of discontinuance varied from the last week in July to the first week in September, but was usually in the latter half of August.

Because weevils fly in from the untreated cotton, weevil control is much more difficult on plots surrounded by fields of undusted cotton, and to obtain the same degree of control a much greater number of applications is necessary than where large areas are dusted.

The heavier infestation in the untreated plots caused more squares to shed and the production of flowers to stop earlier in the season than

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in the treated plots. The scarcity of food in the large areas of surrounding untreated fields caused field migration to begin while the treated plots were still fruiting and made control more difficult late in the season.

CONTROL OF OTHER INSECTS

In all these tests an effort was also made to control other cotton insects, such as the cotton leaf worm (*Alabama argillacea* Hbn.), the cotton flea hopper (*Psallus seriatus* Reut.), and the tarnished plant bug (*Lygus pratensis* L.), in both the treated and the untreated plots, in order that the results might furnish a true measure of injury done by the bollweevil alone. For the control of the cotton leaf worm, 1 pound of paris green mixed with 4 pounds of hydrated lime or 3 pounds of hydrated lime and 1 pound of flour was used at the rate of 10 pounds per acre. Control of the cotton flea hopper and the tarnished plant bug was necessary during 1 year (1926) of the 15-year period, and this was accomplished by using dusting sulphur at the rate of 8 to 12 pounds per acre. During many years of this period nicotine dust was applied to the treated plots, when necessary, to control infestations of the cotton aphid (*Aphis gossypii* Glov.), but in the untreated plots this was necessary only in several tests in 1934. The nicotine dust was home-made and consisted of a mixture of commercial 40-percent nicotine sulphate and either hydrated lime or calcium arsenate.

RESULTS

CALCIUM ARSENATE APPLICATIONS

For each treated plot the period of treatment, the total number of applications, the number of effective applications, and the average number of pounds of calcium arsenate per acre per application used to control the bollweevil are summarized in tables 1 to 5, inclusive. The number of effective applications is the total number of applications minus those that were washed off by rain within 24 hours. The average number of pounds of calcium arsenate per acre per application for each plot was calculated from the total number of applications made. The weather conditions at the time of each application are not included in the tables, as practically all the applications were made in the presence of dew when the atmosphere was calm.

These data for the three seasonal infestations on which control tests were conducted in 1920 are given in table 1. From this table it is seen that the earlier the infestation the earlier it was necessary to start the applications and the more applications were required for control of the bollweevil.

TABLE 1.—*Calcium arsenate treatments used to control early, intermediate, and late infestations of the bollweevil, Madison Parish, La., 1920*

Infestation	Cut no.[1]	Period of treatment	Applications		Average quantity of calcium arsenate per acre per application
			Total	Effective	
			Number	*Number*	*Pounds*
Early	Shirley E	July 28 to Aug. 25	8	6	7.88
	Montrose B	July 10 to Aug. 21	9	8	7.98
	Scotland A	July 15 to Aug. 24	10	8	7.80
	Average		9.0	7.3	[2] 7.89
Intermediate	Montrose I	July 28 to Aug. 24	7	5	8.66
	Montrose J	do	7	5	7.18
	Evergreen D	do	6	5	6.21
	Evergreen E	do	7	5	6.97
	Glen Mary E	July 27 to Aug. 25	7	6	11.63
	Average		6.8	5.2	[2] 7.79
Late	Montrose A	July 28 to Aug. 10	4	3	5.30
	Glen Mary A	July 31 to Aug. 25	6	5	9.87
	Average		5.0	4.0	[2] 7.50
Average			7.1	5.6	[2] 7.79

[1] In the designations of the cut numbers the name represents the plantation and the letter the particular test, or cut, on that plantation.
[2] Weighted averages.

Table 2 gives the data for the regular control tests conducted each year from 1921 to 1926, and from 1929 to 1934, as well as averages for all tests in the 15-year period, exclusive of those conducted in the western portion of Madison Parish in 1927 and the special tests in 1932. From this table it may be seen that the average number of applications per test, both total and effective, was greatest in those years when it was necessary to begin applications early in the season. Furthermore, in those years when the average number of applications per test was low a larger proportion of these applications were effective than when the average number of applications was high. Those years with the heaviest rainfall during the summer months usually had the heaviest infestation; consequently a greater number of applications were necessary and a larger proportion of the applications were lost by rain than in a summer with light rainfall.

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TABLE 2.—*Calcium arsenate treatments used to control the bollweevil, Madison Parish, La., 1921–26 and 1929–34*

Year	Cut no.	Period of treatment	Applications		Average quantity of calcium arsenate per acre per application
			Total	Effective	
			Number	*Number*	*Pounds*
1921	Evergreen D	June 21 to Aug. 17	12	10	5.27
	Glen Mary D	June 22 to Aug. 17	11	10	7.02
	Glen Mary E	do	12	11	6.23
	Montrose E	July 2, to Aug. 27	14	13	6.39
	Montrose F	July 2, to Aug. 22	13	12	4.81
	Shirley A	July 1 to Aug. 27	12	10	5.23
	Average		12.3	11.0	[1] 5.67
1922	Evergreen A	June 24, to Aug. 7	10	7	7.71
	Hermione A	June 24 to Aug. 12	10	10	6.62
	Hermione B	do	9	9	5.92
	Montrose D	June 27 to Aug. 23	11	11	6.89
	Montrose F	June 27 to Aug. 19	10	9	5.27
	Shirley D	June 28 to Aug. 7	9	9	5.66
	Shirley E	June 28 to Aug. 19	10	10	5.44
	Shirley I	June 23 to Aug. 19	12	12	4.74
	Average		10.1	9.6	[1] 5.93
1923	Glen Mary A	July 20 to Aug. 15	6	6	11.63
	Glen Mary C	July 20 to Aug. 10	5	5	7.76
	Islington H	July 18 to Aug. 11	5	5	7.49
	Montrose F	July 14 to Aug. 25	9	9	6.80
	Shirley A	July 7 to Aug. 20	8	8	8.38
	Shirley B	do	8	8	6.35
	Average		6.8	6.8	[1] 7.64
1924	Gilfoil D	July 26 to Aug. 5	3	3	8.98
	Montrose C	July 23 to Aug. 8	4	4	6.63
	Montrose F	July 16 to Aug. 1	5	4	7.84
	Montrose T	July 24 to Aug. 8	4	3	8.30
	Montrose W	July 31 to Aug. 4	2	2	5.39
	Average		3.6	3.2	[1] 7.62
1925	Hecla A	July 7 to Aug. 3	5	5	5.56
	Hecla B	July 11 to July 29	4	4	5.42
	Hecla G	July 20 to Aug. 3	4	4	4.80
	Sparta A	July 9 to Aug. 3	5	5	5.31
	Sparta C	do	5	5	5.27
	Average		4.6	4.6	[1] 5.27
1926	Hecla B	June 16 to Aug. 24	12	10	6.11
	Hecla E	do	12	11	5.71
	Islington C	June 19 to Aug. 27	14	11	7.14
	Islington D	do	14	11	6.69
	Montrose L	July 1 to Aug. 28	10	10	6.49
	Average		12.4	10.6	[1] 6.25
1929	Evergreen A	July 12 to Aug. 7	5	5	6.30
	Hecla A	July 3 to Aug. 6	9	6	6.69
	Hecla F	July 10 to Aug. 10	7	7	7.72
	Maxwellton B	July 9 to Aug. 15	8	7	6.38
	Montrose B	July 15 to Aug. 15	8	7	6.86
	Montrose F	July 10 to Aug. 16	8	8	6.16
	Montrose G	July 11 to Aug. 16	7	7	6.77
	Montrose M	July 10 to Aug. 26	10	9	6.84
	Talla Bena A	June 25 to Aug. 15	11	8	7.47
	Average		8.1	7.1	[1] 6.84
1930	Evergreen D	July 11 to Aug. 4	4	4	6.52
	Islington A	July 12 to Aug. 3	4	4	6.88
	West Point A	July 11 to Aug. 2	4	4	6.29
	West Point B	July 11 to Aug. 3	4	4	6.45
	Average		4	4	[1] 6.52

[1] Weighted averages.

TABLE 2.—*Calcium arsenate treatments used to control the bollweevil, Madison Parish, La., 1921–26 and 1929–34*—Continued

Year	Cut no.	Period of treatment	Applications		Average quantity of calcium arsenate per acre per application
			Total	Effective	
			Number	*Number*	*Pounds*
1931	Dalkeith A	July 14 to Aug. 22	9	9	6.30
	Dalkeith C	do	9	9	5.58
	Evergreen A	July 17 to Aug. 26	11	9	6.12
	Evergreen C	June 29 to Aug. 26	13	11	6.24
	Evergreen D	July 23 to Aug. 22	8	7	6.14
	Hecla C	July 9 to Aug. 21	11	9	5.31
	Hecla H	July 22 to Aug. 21	9	6	5.25
	Islington D	July 23 to Aug. 31	10	9	7.08
	Scotland A	July 17 to Aug. 29	11	9	7.93
	West Point A	June 29 to Aug. 14	10	8	5.35
	Average		10.1	8.6	[1] 6.16
1932	Dalkeith A	June 27 to Aug. 6	10	8	6.41
	Dalkeith B	July 8 to Aug. 6	8	7	5.29
	Dalkeith C	do	8	7	6.12
	Dalkeith D	June 27 to Aug. 6	11	9	5.99
	Dalkeith E	do	10	8	4.96
	Evergreen A	July 9 to Aug. 15	11	8	5.38
	Evergreen B	June 28 to Aug. 5	11	8	6.95
	Evergreen C	June 28 to Aug. 15	14	10	5.45
	Islington C	July 9 to Aug. 15	12	8	5.58
	Average		10.6	8.1	[1] 5.56
1933	Evergreen A	June 28 to Aug. 9	10	9	7.26
	Evergreen B	July 8 to Aug. 16	11	6	7.31
	Evergreen C	July 13 to Aug. 16	10	5	8.14
	Islington A	July 3 to Aug. 16	10	9	5.99
	Lane A	July 14 to Aug. 11	8	7	5.30
	Lane B–3	July 14 to Aug. 17	9	8	5.33
	Lane B–5	do	9	8	5.41
	Montrose A	July 6 to Aug. 25	11	8	6.91
	Will Sevier A	July 15 to Aug. 16	8	4	5.58
	Average		9.6	7.1	[1] 6.37
1934	Dalkeith A	June 28 to Aug. 7	10	10	5.59
	Dalkeith B	do	10	10	5.97
	Dalkeith C	do	10	10	5.26
	Evergreen B	July 8 to Aug. 11	10	8	5.73
	Islington A	July 10 to Aug. 1	7	5	6.05
	Islington B	July 3 to Aug. 1	8	6	6.42
	Islington D	do	8	6	6.04
	Islington F	July 20 to Aug. 8	6	5	5.00
	Islington G	July 3 to Aug. 1	8	6	6.94
	Islington H	June 30 to Aug. 11	12	9	6.02
	Islington I	July 8 to Aug. 11	10	7	5.83
	Islington J	do	10	7	5.84
	Islington K	June 30 to Aug. 6	11	8	5.56
	Maxwellton A	July 7–28	6	6	5.53
	Maxwellton B	do	5	5	5.42
	Maxwellton C	do	5	5	5.61
	Maxwellton D	do	6	6	5.91
	Average		8.4	7.0	[1] 5.84
Average [2]			8.4	7.2	[1] 6.32

[1] Weighted averages.

[2] These averages include, in addition to the averages of the regular tests given in this table, the averages obtained in the special tests in 1920 (table 1) and 1928 (table 4), and those in the eastern portion of Madison Parish in 1927 (table 3).

The calcium arsenate applications made in the three series of tests during 1927 are summarized in table 3. It is seen that the average total number of applications per test was nearly the same in all three series, but that the average number of effective applications per test was less in both the eastern and the western portions of Madison Parish on cotton planted after the flood waters had receded than on cotton planted at the usual time.

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TABLE 3.—*Effect of flooding and consequent late planting of cotton on the quantity of calcium arsenate used to control the bollweevil, Madison Parish, La., 1927*

Time of planting	Condition of fields	Location of fields in Madison Parish	Cut no.	Period of treatment	Applications		Average quantity of calcium arsenate per acre per application
					Total	Effective	
					Number	*Number*	*Pounds*
Apr. 1–15	Not flooded.	Eastern	Evergreen A	July 8 to Aug. 8	8	7	8.35
			Islington A	July 14 to Aug. 9	6	6	5.33
			Islington B	do	6	6	5.17
			Average		6.7	6.3	[1] 6.11
		do	Evergreen B	Aug. 9 to Sept. 6	7	5	6.02
			Islington C	Aug. 9 to Sept. 2	6	5	6.78
			Islington G	do	6	5	6.99
			Laclede A	Aug. 8 to Sept. 7	7	7	7.89
			Laclede B	Aug. 8 to Sept. 2	6	6	7.53
			Lowbanks B	Aug. 5 to Sept. 5	8	6	8.02
			Average		6.7	5.7	[1] 7.19
Last week in May to June 10.	Flooded	Western	Arcola A	Aug. 10 to Sept. 7	7	6	6.32
			Arcola B	Aug. 10 to Sept. 2	6	5	7.63
			Little Waverly A	Aug. 11 to Sept. 7	8	5	10.13
			Little Waverly B	Aug. 15 to Aug. 29	4	3	8.73
			Waverly A	Aug. 4 to Aug. 27	5	5	5.91
			Waverly B	Aug. 4 to Sept. 2	8	7	6.14
			Waverly C	Aug. 4 to Sept. 7	8	8	6.73
			Waverly D	Aug. 4 to Sept. 1	8	6	5.43
			Average		6.8	5.6	[1] 6.65
Average		Eastern			6.7	5.9	[1] 6.77

[1] Weighted averages.

The data for the calcium arsenate applications made in 1928 on land that was, and that was not, planted to cotton in 1927 are summarized in table 4. The average total number of applications per test on land planted to cotton in 1927 was greater than on land not planted to cotton, and there was a very slight difference in the average number of effective applications per test and in the average quantity of calcium arsenate used per application.

TABLE 4.—*Calcium arsenate treatments used to control the bollweevil in Madison Parish, La., in 1928 on land that was and on land that was not planted to cotton in 1927*

Planted to cotton in 1927?	Cut no.	Period of treatment	Applications		Average quantity of calcium arsenate per acre per application
			Total	Effective	
			Number	*Number*	*Pounds*
No	Dalkeith A	July 18 to Aug. 11	6	4	5.13
	Montrose G	July 10 to Aug. 11	6	6	5.97
	Montrose H	June 28 to Aug. 11	7	7	5.28
	Montrose I	July 10 to Aug. 28	8	8	5.61
	Montrose J	July 10 to Sept. 4	11	11	6.48
	Average		7.6	7.2	[1] 5.70
Yes	Islington E	July 19 to Aug. 15	7	5	6.19
	Maxwellton B	July 10 to Aug. 28	11	11	5.80
	Montrose D	July 9 to Aug. 10	9	5	5.09
	Richmond A	July 14 to Aug. 20	11	6	6.43
	Talla Bena A	June 23 to Aug. 8	10	10	5.00
	Average		9.6	7.4	[1] 5.76
Average			8.6	7.3	[1] 5.73

[1] Weighted averages.

Table 5 summarizes the data for the calcium arsenate applications made in 1932 late in the season when there was a heavy square infestation. These tests were conducted on very fertile land which was then in cultivation for the third year and produced an unusually rank cotton growth. A larger quantity of calcium arsenate per acre per application was necessary than when the treatments were begun earlier in the season, because at this time the plants were larger.

TABLE 5.—*Calcium arsenate treatments used to control the bollweevil when the treatments were begun late in the season when there was a heavy square infestation, Madison Parish, La., 1932*

Cut no.	Period of treatment	Applications		Average quantity of calcium arsenate per acre per application
		Total	Effective	
		Number	*Number*	*Pounds*
Barnes A	July 19 to Sept. 7	14	13	7.66
Englewood A	Aug. 4 to Sept. 7	9	9	6.72

EFFECT OF TREATMENTS ON SQUARE INFESTATION

The average weekly square infestation in the tests conducted in 1920 with early, intermediate, and late infestations is given in table 6. The difference in the percentage of square infestation in the treated and untreated plots after the beginning of treatments shows that calcium arsenate was most effective against an early infestation, less effective against an intermediate infestation, and least effective against a late infestation. The square infestation on the final record of each series was very high on account of the scarcity of squares due to maturity of the plants, and also because field migration of weevils was in progress.

TABLE 6.—*Weekly square infestation in control tests with early, intermediate, and late infestations of the bollweevil, Madison Parish, La., 1920*

Infestation	Tests	Week beginning—	Average squares infested		Infestation	Tests	Week beginning—	Average squares infested	
			In untreated plots	In treated plots				In untreated plots	In treated plots
	Number		*Percent*	*Percent*		*Number*		*Percent*	*Percent*
Early	3	June 17	9.8	9.6	Late	2	June 17	2.3	2.9
		June 24	9.7	6.9			June 24	1.7	.6
		July 1	9.8	11.4			July 1	2.1	2.1
		July 8[1]	8.8	9.0			July 8	1.3	1.7
		July 15	12.2	8.7			July 15	11.0	5.8
		July 22	15.8	13.2			July 22[1]	18.4	27.1
		July 29	46.6	28.0			July 29	28.9	31.4
		Aug. 5	45.0	15.6			Aug. 5	59.5	28.4
		Aug. 12	70.3	35.3			Aug. 12	68.8	71.1
		Aug. 19	86.6	82.3			Aug. 19	85.3	73.3
Intermediate	5	June 17	5.5	5.6	All tests	10	June 17	5.8	5.9
		June 24	4.4	3.9			June 24	5.5	4.2
		July 1	5.8	2.8			July 1	6.6	6.1
		July 8	1.6	1.9			July 8	4.2	4.5
		July 15	7.8	8.4			July 15	9.8	8.0
		July 22[1]	18.8	16.8			July 22	18.2	18.0
		July 29	23.3	13.8			July 29	33.4	23.5
		Aug. 5	45.2	18.2			Aug. 5	48.3	19.9
		Aug. 12	64.0	33.9			Aug. 12	67.5	41.9
		Aug. 19	80.5	77.3			Aug. 19	84.1	77.6

[1] Week during which calcium arsenate treatments were begun.

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The average weekly square infestation in the regular control tests conducted from 1921 to 1926 and from 1929 to 1934 is given in table 7.

TABLE 7.—*Weekly square infestations in control tests against the bollweevil, Madison Parish, La., 1921–26 and 1929–34*

Year	Tests	Week beginning—	Average squares infested	
			In untreated plots	In treated plots
	Number		*Percent*	*Percent*
1921	6	June 17[1]	15.0	10.6
		June 24	14.2	12.6
		July 1	15.2	4.2
		July 8	8.9	4.1
		July 15	14.2	8.2
		July 22	23.2	6.1
		July 29	44.7	7.6
		Aug. 5	62.5	17.0
		Aug. 12	78.0	19.0
		Aug. 19	82.6	39.0
1922	8	June 17[1]	17.0	11.3
		June 24	16.2	14.2
		July 1	9.2	7.4
		July 8	19.2	8.0
		July 15	33.3	7.1
		July 22	40.9	10.9
		July 29	62.2	13.5
		Aug. 5	68.1	30.2
1923	6	June 17	6.9	4.7
		June 24	2.7	3.3
		July 1[1]	3.5	7.7
		July 8	4.1	4.5
		July 15	8.8	8.8
		July 22	16.4	5.8
		July 29	20.6	8.8
		Aug. 5	33.5	17.7
		Aug. 12	46.0	8.1
		Aug. 19	59.5	7.8
1924	5	June 17	.8	.4
		June 24	2.4	2.8
		July 1	2.3	2.0
		July 8	2.6	5.5
		July 15[1]	5.7	4.6
		July 22	8.3	8.8
		July 29	15.3	2.2
		Aug. 5	18.5	2.7
1925	5	June 17	.4	.0
		June 24	2.3	1.7
		July 1[1]	7.3	5.7
		July 8	10.3	11.1
		July 15	14.5	7.5
		July 22	32.4	12.9
		July 29	29.2	17.0
		Aug. 5	70.6	49.8
1926	5	June 17[1]	6.6	6.0
		June 24	4.5	2.2
		July 1	9.3	4.8
		July 8	15.6	10.3
		July 15	15.9	8.6
		July 22	31.1	6.5
		July 29	47.6	29.4
		Aug. 5	54.3	34.1
		Aug. 12	67.1	25.0
		Aug. 19	78.2	46.6
1929	9	June 10	5.2	7.6
		June 17	6.2	4.6
		June 24[1]	3.1	4.1
		July 1	5.8	5.9
		July 8	13.6	7.3
		July 15	19.9	5.7
		July 22	26.2	5.2
		July 29	34.2	13.5
		Aug. 5	46.4	22.6
		Aug. 12	57.0	23.3
1930	4	June 17	5.0	17.8
		June 24	12.3	9.2
		July 1	1.3	4.7
		July 8[1]	8.2	8.9
		July 15	6.3	3.7
		July 22	7.1	.3
		July 29	4.6	.4
		Aug. 5	7.7	.9
1931	10	June 17	1.2	1.7
		June 24[1]	2.4	3.1
		July 1	1.2	2.8
		July 8	5.4	4.9
		July 15	10.8	8.0
		July 22	22.2	8.5
		July 29	41.1	14.0
		Aug. 5	56.0	15.8
		Aug. 12	70.8	18.0
		Aug. 19	74.0	27.6
1932	9	June 10	18.9	16.4
		June 17	18.2	20.5
		June 24[1]	22.5	21.7
		July 1	29.2	20.0
		July 8	48.7	19.9
		July 15	64.9	15.8
		July 22	76.7	18.3
		July 29	86.2	48.0
1933	9	June 17	8.3	8.1
		June 24[1]	8.4	8.5
		July 1	8.7	8.1
		July 8	17.6	12.2
		July 15	25.7	11.7
		July 22	46.5	29.3
		July 29	63.4	36.1
		Aug. 5	48.6	21.8
1934	17	June 17	16.2	16.2
		June 24[1]	15.4	15.7
		July 1	23.3	22.4
		July 8	35.5	20.3
		July 15	46.0	14.4
		July 22	53.5	13.5
		July 29	76.1	24.1

[1] Week during which calcium arsenate treatments were begun.

The infestations in 1921 and 1922 were similar. In both years there was a fairly heavy infestation at the beginning of the season, which increased rapidly in the untreated plots after the middle of July, but the calcium arsenate treatments were effective until the final weekly period. It was possible to continue these records later in the season in 1921 than in 1922, since the cotton matured later in the former year.

In 1923 the early infestation was much lighter than in either 1921 or 1922, and the calcium arsenate treatments were very effective during the five weekly periods beginning July 22.

The square infestation in 1924 was very light during the entire season, and the only noticeable difference between the treated and the untreated plots was shown in the records of the weekly periods beginning July 29 and August 5.

In 1925 the infestation was very light early in the season and beginning with July 15 it increased rapidly in the untreated plots, except during the weekly period beginning July 29, but in each of the last four weekly periods it was much lower in the treated than in the untreated plots. The great increase in the infestation of the treated and the untreated plots of the final weekly period, beginning August 5, was due to the scarcity of squares and to field migration of weevils.

In 1926 the average square infestation was much higher at the beginning of the season than in 1925. After treatments were started it was much lower in the treated plots than in the untreated plots in all the counts made, although during the last four weekly periods it was somewhat high on account of field migration of weevils.

In 1929 the average square infestation at the beginning of the season was similar to that in 1926, but it increased more slowly as the season advanced. The untreated and the treated plots were about equally infested from June 10 to July 7, but after July 8, when most of the treatments were made, the infestation was much lower in the treated plots.

In 1930 there was a fairly heavy infestation in June in all plots, but in all counts made after treatment was started the infestation was less in the treated than in the untreated plots. At no time, however, was the infestation in the untreated plots heavy enough to cause any serious damage, and the average infestation was less in July and August than in June.

In 1931 there was a low square infestation in both the untreated and the treated plots during the first half of the season, but during the latter half of the season the infestation in the untreated plots increased rapidly while in the treated plots the calcium arsenate controlled the infestation.

In 1932 the infestation at the beginning of the season was the highest of any year of the 15-year period. In many of the tests the average infestation was above 10 percent when calcium arsenate treatments were started, and although these treatments failed to reduce the infestation to below 10 percent, sufficient control was obtained to give good increases in yield.

In 1933 the infestation at the beginning of the season was heavier than normal but less than half as heavy as in 1932 and remained practically stationary during the first three weekly periods. Beginning with July 8 and continuing throughout the remainder of the season, the infestation was much lighter in the treated than in the untreated plots. The decrease in the infestation of both untreated and treated plots on the final record was probably due to climatic control of the weevils.

In 1934 the infestation during the week beginning June 17 was almost as heavy as during the same period in 1932, but because of unfavorable climatic conditions it did not increase so rapidly. The infestations in the treated and in the untreated plots were very nearly equal during each of the first three weekly periods, but that

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in the treated plots was much lower during the remaining weekly periods. The weather during July and August was dry and hot, causing heavy climatic control and early maturity of the plants. From July 15 to the end of the season squares were very scarce in most tests, which caused the percentages of infestation to be much greater than they would have been had the normal number of squares per plant been present.

The average square infestation for all the regular tests recorded in table 7 and discussed in the foregoing paragraphs is presented graphically in figure 1.

The average infestations in the tests conducted in 1927 are given by weekly periods in table 8. Counts in the tests with cotton planted at the usual time on land not flooded indicated that weevils, after emerging from hibernation, concentrated early in these fields, all of which were located at a considerable distance from timber and in normal years were not heavily infested until late in July or in the first part of August. Counts made in the flooded areas on cotton planted after the flood waters had receded show a very low square infestation prior to August 5, but after this date the infestation in the untreated plots increased and in the treated plots the calcium arsenate was effective. It is interesting to note that the square infestation in late-planted fields was so low that calcium arsenate applications were not needed until the cotton planted at the usual time was practically mature and very heavily infested, and weevils were migrating from the early planted cotton to these fields where squares were more abundant. The square infestation on late-planted cotton averaged higher in the western than in the eastern portion of Madison Parish, indicating that more weevils migrated to the former, which was nearer to the unflooded hill sections of another parish, than to the latter.

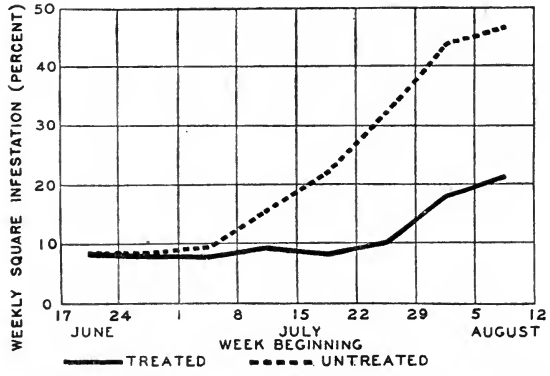

FIGURE 1.—Average of weekly square infestations found in regular tests conducted during 1921–34.

TABLE 8.—*Effect of flooding and consequent late planting on the weekly square infestations in control tests against the bollweevil, Madison Parish, La., 1927*

Time of planting	Condition of fields	Location of fields in Madison Parish	Tests	Week beginning—	Average squares infested	
					In untreated plots	In treated plots
			Number		*Percent*	*Percent*
Apr. 1–15	Not flooded	Eastern	3	July 1	13.2	10.9
				July 8[1]	28.2	21.9
				July 15	33.6	14.4
				July 22	44.6	14.1
				July 29	61.1	35.3
Last week in May to June 10	Flooded	do	6	July 8	.2	.7
				July 15	.5	.8
				July 22	.9	.6
				July 29	2.6	4.0
				Aug. 5[1]	10.2	8.5
				Aug. 12	19.9	5.5
				Aug. 19	33.8	4.5
				Aug. 26	65.9	13.2
		Western	8	July 8	.5	4.0
				July 15	1.1	1.2
				July 22	1.1	1.0
				July 29[1]	4.7	6.2
				Aug. 5	15.5	10.3
				Aug. 12	28.9	8.3
				Aug. 19	49.6	13.2
				Aug. 26	63.2	30.2
				Sept. 2	86.8	24.0

[1] Week during which calcium arsenate treatments were begun.

Table 9 gives the average square infestation by weekly periods in the control tests made in 1928 in fields not planted to cotton and in fields planted to cotton in 1927. The average square infestation in the untreated plots was higher during the entire season where cotton had been grown in 1927 than where cotton had not been grown. Calcium arsenate treatments were very effective in both series of tests. During the last two weekly periods the average square infestation was much lower in the treated plots located on land that had been planted in cotton during 1927.

TABLE 9.—*Weekly square infestation on land that was, and on land that was not, planted to cotton in 1927, in control tests against the bollweevil, Madison Parish, La., 1928*

Week beginning[1]—	Average squares infested				Week beginning[1]—	Average squares infested			
	Land not planted to cotton in 1927		Land planted to cotton in 1927			Land not planted to cotton in 1927		Land planted to cotton in 1927	
	In untreated plots	In treated plots	In untreated plots	In treated plots		In untreated plots	In treated plots	In untreated plots	In treated plots
	Percent	*Percent*	*Percent*	*Percent*		*Percent*	*Percent*	*Percent*	*Percent*
June 17[2]	2.0	0.7	16.8	18.5	July 22	17.7	3.9	31.9	5.8
June 24[3]	2.6	4.3	7.6	6.1	July 29	32.7	27.1	44.2	18.7
July 1	3.3	2.8	17.2	6.4	Aug. 5	42.8	14.9	56.5	22.0
July 8	5.7	3.3	13.8	7.6	Aug. 12	64.2	18.5	68.2	3.5
July 15	8.1	2.9	21.4	9.7	Aug. 19	66.1	26.4	88.2	4.5

[1] Each weekly record is the average of 5 tests.
[2] Week during which calcium arsenate treatments were begun in fields planted to cotton in 1927.
[3] Week during which calcium arsenate treatments were begun in fields not planted to cotton in 1927.

The average square infestation for the two special tests in 1932 to determine the effectiveness of treatments made late in the season, when field migration of weevils was in progress and the infestation was

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very heavy, is given in table 10. The counts made after the first week show a lower percentage infestation in the treated than in the untreated plots.

TABLE 10.—*Weekly square infestation in control tests against the bollweevil, where treatments were begun late in the season when the square infestation was heavy, Madison Parish, La., 1932*

Cut no.	Week beginning—	Average squares infested		Cut no.	Week beginning—	Average squares infested	
		In untreated plots	In treated plots			In untreated plots	In treated plots
		Percent	*Percent*			*Percent*	*Percent*
Barnes A	July 18[1]	88.0	87.3	Englewood A	Aug. 1[1]	88.0	89.8
	July 25	79.7	43.8		Aug. 8	87.3	71.7
	Aug. 1	90.0	79.3		Aug. 15	85.0	47.5
	Aug. 8	78.3	55.2		Aug. 22	85.7	37.8
	Aug. 15	84.7	20.7		Aug. 29	91.5	60.8
	Aug. 22	89.7	47.5		Sept. 5	91.3	58.5
	Aug. 29	88.7	59.8		Sept. 12	89.0	49.0
	Sept. 5	87.0	43.2				
	Sept. 12	85.3	43.8				

[1] In both tests the calcium arsenate treatments were begun during the first week of record.

EFFECT OF TREATMENTS ON YIELD OF COTTON

The yield records for the tests conducted in 1920 are given in table 11. It is seen that the calcium arsenate treatments gave greatest increased yields with an early infestation, less with an intermediate, and least with a late infestation.

TABLE 11.—*Seed-cotton production in control tests with early, intermediate, and late bollweevil infestations, Madison Parish, La., 1920*

Infestation	Cut no.	Seed cotton produced per acre		Increase in yield of treated plots over that of untreated plots	
		In untreated plots	In treated plots		
		Pounds	*Pounds*	*Pounds per acre*	*Percent*
Early	Shirley E	851	1,280	429	50.4
	Montrose B	768	1,062	294	38.3
	Scotland A	601	852	251	41.8
	Average	740	1,065	325	43.9
Intermediate	Montrose I	1,067	1,322	255	23.9
	Montrose J	969	1,320	351	36.2
	Evergreen D	681	1,073	392	57.6
	Evergreen E	815	987	172	21.1
	Glen Mary E	638	907	269	42.2
	Average	834	1,122	288	34.5
Late	Montrose A	665	828	163	24.5
	Glen Mary A	1,418	1,616	198	14.0
	Average	1,042	1,222	180	17.3
Average		847	1,125	278	32.8

Table 12 gives the production and the increase in the yield of the treated plots over that of the untreated plots for the years 1921–26 and 1929–34, and the average for the entire 15-year period. Remarkable increases were shown in most of the treated plots in 1921 and 1922, but the increases in 1923 were not so great. In 1924 the untreated plot in three tests produced more cotton per acre than the treated plot. This was probably due to a slight difference in soil

fertility, for the infestation was so low during the entire season that little increase in the yields of the treated plots could be expected. The average yield for the five tests was only 10 pounds per acre greater in the treated than in the untreated plots. In 1925 all the treated plots showed small to medium increases in yield over the untreated plots. In 1926 there were large increases in yield in the treated plots, the average increase being 742 pounds per acre, which was the largest recorded in the 15-year period. The untreated plots in 3 of the 9 tests conducted in 1929 produced more cotton per acre than the treated plots. The differences in yield in these three tests were very slight, probably owing to variation in soil fertility and to a light infestation. The average yield for the nine tests was greater in the treated than in the untreated plots. In 2 of the 4 tests conducted in 1930 the untreated plots produced more cotton per acre than the treated plots, which also may have been due to difference in soil fertility. However, the average yield in the treated plots was 105 pounds per acre greater than in the untreated plots. An increased yield was shown in the treated plot of each test conducted during 1931 and 1932, and in most tests the increases were large. In 1933 each of the 9 treated plots produced more cotton per acre than the corresponding untreated plots, these increases ranging from 187 to 617 pounds and averaging 419 pounds per acre. In 2 of the 17 tests conducted in 1934 the untreated plots produced more cotton per acre than the treated plots. In each of these two tests the infestation was light and the soil appeared to be more fertile in the untreated plot. The increases for the treated plots in many of the 15 remaining tests were small and ranged from 36 to 730 pounds per acre, and the average increase for the 17 treated plots was 236 pounds per acre.

TABLE 12.—*Seed-cotton production in regular control tests against the bollweevil, Madison Parish, La., 1921–26 and 1929–34*

Year	Cut no.	Seed cotton produced per acre		Increase or decrease (−) in yield of treated plots over that of untreated plots	
		In untreated plots	In treated plots		
		Pounds	*Pounds*	*Pounds per acre*	*Percent*
1921	Evergreen D	922	1,475	553	60.0
	Glen Mary D	1,044	1,312	268	25.7
	Glen Mary E	986	1,063	77	7.8
	Montrose E	880	1,307	427	48.5
	Montrose F	729	1,346	617	84.6
	Shirley A	1,277	1,936	659	51.6
	Average	973	1,407	434	44.6
1922	Evergreen A	862	966	104	12.1
	Hermione A	486	1,204	718	147.7
	Hermione B	535	1,060	525	98.1
	Montrose D	360	1,066	706	196.1
	Montrose F	925	1,206	281	30.4
	Shirley D	562	898	336	59.8
	Shirley E	533	1,031	498	93.4
	Shirley I	523	1,367	844	161.4
	Average	598	1,100	502	83.9
1923	Glen Mary A	1,467	1,648	181	12.3
	Glen Mary C	839	973	134	16.0
	Islington H	1,544	1,722	178	11.5
	Montrose F	668	825	157	23.5
	Shirley A	1,069	1,424	355	33.2
	Shirley B	1,214	1,620	406	33.4
	Average	1,134	1,369	235	20.7

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TABLE 12.—*Seed-cotton production in regular control tests against the bollweevil, Madison Parish, La., 1921–26 and 1929–34*—Continued

Year	Cut no.	Seed cotton produced per acre		Increase or decrease (−) in yield of treated plots over that of untreated plots	
		In untreated plots	In treated plots		
		Pounds	*Pounds*	*Pounds per acre*	*Percent*
1924	Gilfoil D	1,206	1,253	47	3.9
	Montrose C	940	922	−18	−1.9
	Montrose F	1,329	1,321	−8	−.6
	Montrose T	571	547	−24	−4.2
	Montrose W	706	757	51	7.2
	Average	950	960	10	1.1
1925	Hecla A	2,251	2,577	326	14.5
	Hecla B	1,698	1,856	158	9.3
	Hecla G	2,173	2,561	388	17.9
	Sparta A	2,032	2,123	91	4.5
	Sparta C	1,715	1,902	187	10.9
	Average	1,974	2,204	230	11.7
1926	Hecla B	1,227	1,600	373	30.4
	Hecla E	1,390	2,100	710	51.1
	Islington C	633	2,194	1,561	246.6
	Islington D	1,224	2,056	832	68.0
	Montrose L	962	1,194	232	24.1
	Average	1,087	1,829	742	68.3
1929	Evergreen A	1,753	1,685	−68	−3.9
	Hecla A	1,694	1,765	71	4.2
	Hecla F	1,454	1,426	−28	−1.9
	Maxwellton B	1,436	1,419	−17	−1.2
	Montrose B	1,680	1,948	268	16.0
	Montrose F	1,519	1,621	102	6.7
	Montrose G	1,562	1,761	199	12.7
	Montrose M	1,276	1,972	696	54.5
	Talla Bena A	1,021	1,360	339	33.2
	Average	1,488	1,662	174	11.7
1930	Evergreen D	1,159	1,133	−26	−2.2
	Islington A	2,040	2,443	403	19.8
	West Point A	660	777	117	17.7
	West Point B	663	592	−71	−10.7
	Average	1,131	1,236	105	9.3
1931	Dalkeith A	1,646	2,208	562	34.1
	Dalkeith C	2,273	2,673	400	17.6
	Evergreen A	2,226	2,737	511	23.0
	Evergreen C	2,137	3,011	874	40.9
	Evergreen D	1,643	1,973	330	20.1
	Hecla C	1,754	2,181	427	24.3
	Hecla H	1,940	2,264	324	16.7
	Islington D	1,652	2,715	1,063	64.3
	Scotland A	1,553	2,443	890	57.3
	West Point A	2,026	2,635	609	30.1
	Average	1,885	2,484	599	31.8
1932	Dalkeith A	1,521	1,787	266	17.5
	Dalkeith B	1,696	1,837	141	8.3
	Dalkeith C	1,477	1,615	138	9.3
	Dalkeith D	993	1,688	695	70.0
	Dalkeith E	1,105	1,592	487	44.1
	Evergreen A	819	1,952	1,133	138.3
	Evergreen B	804	1,544	740	92.0
	Evergreen C	1,243	1,895	652	52.5
	Islington C	1,598	2,500	902	56.4
	Average	1,251	1,823	572	45.7
1933	Evergreen A	1,280	1,685	405	31.6
	Evergreen B	811	1,307	496	61.2
	Evergreen C	936	1,468	532	56.8
	Islington A	1,018	1,550	532	52.3
	Lane A	792	1,077	285	36.0
	Lane B–3	846	1,263	417	49.3
	Lane B–5	846	1,463	617	72.9
	Montrose A	654	841	187	28.6
	Will Sevier A	1,012	1,312	300	29.6
	Average	911	1,330	419	46.0

TABLE 12.—*Seed-cotton production in regular control tests against the bollweevil, Madison Parish, La., 1921–26 and 1929–34*—Continued

Year	Cut no.	Seed cotton produced per acre		Increase or decrease (−) in yield of treated plots over that of untreated plots.	
		In untreated plots	In treated plots		
		Pounds	*Pounds*	*Pounds per acre*	*Percent*
1934	Dalkeith A	1,582	1,618	36	2.3
	Dalkeith B	1,132	1,548	416	36.7
	Dalkeith C	1,338	1,652	314	23.5
	Evergreen B	1,085	1,567	482	44.4
	Islington A	1,572	1,556	−16	−1.0
	Islington B	1,365	1,444	79	5.8
	Islington D	1,190	995	−195	−16.4
	Islington F	1,547	1,757	210	13.6
	Islington G	1,037	1,373	336	32.4
	Islington H	1,407	2,008	601	42.7
	Islington I	1,218	1,474	256	21.0
	Islington J	923	1,653	730	79.1
	Islington K	1,217	1,544	327	26.9
	Maxwellton A	1,173	1,369	196	16.7
	Maxwellton B	854	960	106	12.4
	Maxwellton C	887	957	70	7.9
	Maxwellton D	1,082	1,139	57	5.3
	Average	1,212	1,448	236	19.5
Average for 15-year period [1]		1,178	1,534	356	30.2

[1] These averages include, in addition to the averages of the regular tests given in this table, the averages obtained in the special tests in 1920 (table 11) and 1928 (table 14), and those in the eastern portion of Madison Parish in 1927 (table 13).

In table 13, which gives the production in 1927, it is seen that the average increased yield in the treated plots was greater in the tests conducted on cotton that was planted at the usual time than in either series of tests conducted on land that had been flooded where the cotton was planted late after the flood waters had receded. The average increase in the tests on late-planted cotton was greater in the western than in the eastern portion of Madison Parish.

TABLE 13.—*Effect of flooding and consequent late planting on seed-cotton production in control tests against the bollweevil, Madison Parish, La., 1927*

Time of planting	Condition of fields	Location of fields in Madison Parish	Cut no.	Seed cotton produced per acre		Increase in yield of treated plots over that of untreated plots	
				In untreated plots	In treated plots		
				Pounds	*Pounds*	*Pounds per acre*	*Percent*
Apr. 1–15	Not flooded	Eastern	Evergreen A	1,689	2,077	388	23.0
			Islington A	1,311	1,358	47	3.6
			Islington B	856	2,105	1,249	145.9
			Average	1,285	1,847	562	43.7
Last week in May to June 10.	Flooded	do	Evergreen B	767	1,000	233	30.4
			Islington C	1,507	1,862	355	23.6
			Islington G	1,144	1,282	138	12.1
			Laclede A	1,541	2,163	622	40.4
			Laclede B	1,629	2,022	393	24.1
			Lowbanks B	848	1,151	303	35.7
			Average	1,239	1,580	341	27.5
		Western	Arcola A	1,190	1,593	403	33.9
			Arcola B	971	1,372	401	41.3
			Little Waverly A	800	1,235	435	54.4
			Little Waverly B	1,066	1,282	216	20.3
			Waverly A	489	842	353	72.2
			Waverly B	764	1,378	614	80.4
			Waverly C	765	1,308	543	71.0
			Waverly D	823	1,255	432	52.5
			Average	859	1,283	424	49.4
Average		Eastern		1,255	1,669	414	33.0

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Table 14, giving the production for the tests conducted in 1928, shows that the average increase in yield in the treated plots was greatest where cotton had been planted in 1927, indicating greater weevil carry-over and damage in 1928 in these plots than where cotton had not been planted in 1927.

TABLE 14.—*Seed-cotton production in 1928 in control tests against the bollweevil on land that was, and that was not, planted to cotton in 1927, Madison Parish, La.*

Planted to cotton in 1927?	Cut no.	Seed cotton produced per acre		Increase in yield of treated plots over that of untreated plots	
		In untreated plots	In treated plots		
		Pounds	*Pounds*	*Pounds per acre*	*Percent*
No	Dalkeith A	1,589	2,033	444	27.9
	Montrose G	868	932	64	7.4
	Montrose H	681	961	280	41.1
	Montrose I	693	958	265	38.2
	Montrose J	601	1,145	544	90.5
	Average	886	1,206	320	36.1
Yes	Islington E	1,229	1,629	400	32.5
	Maxwellton B	936	1,229	293	31.3
	Montrose D	1,393	1,839	446	32.0
	Richmond A	1,319	1,905	586	44.4
	Talla Bena A	400	1,082	682	170.5
	Average	1,055	1,537	482	45.7
Average		971	1,371	400	41.2

The yield records for two special tests conducted in 1932 to determine the value of calcium arsenate applications made late in the season, when field migration of weevils was in progress and the square infestation was very heavy, are given in table 15. In both tests the yield was very much greater in the treated plot than in the untreated plot. In each test the cotton was planted on fertile delta land that was then in cultivation for the third year, and it fruited much later than is usual on delta land; therefore, the yields were much greater than could have been expected on less fertile land. Furthermore, the weevil infestation was so heavy early in the season that at the time treatments were started few bolls had been set.

TABLE 15.—*Seed-cotton production in control tests against the bollweevil where treatments were begun late in the season when there was a heavy square infestation, Madison Parish, La., 1932*

Cut no.	Seed cotton produced per acre		Increase in yield of treated plots over that of untreated plots	
	In untreated plots	In treated plots		
	Pounds	*Pounds*	*Pounds per acre*	*Percent*
Barnes A	507	2,126	1,619	319.3
Englewood A	1,079	1,896	817	75.7

EFFECT OF MINIMUM WINTER TEMPERATURES ON THE EFFECTIVENESS OF THE TREATMENTS

The minimum winter temperatures influence the effectiveness of the calcium arsenate treatments indirectly by their effect on the weevils' survival and emergence from hibernation as measured by the number of plants per weevil in May and June. These counts were made each year except 1927, when they were omitted on account of the overflow. During 4 (1924, 1925, 1928, and 1930) of the 6 years in which the minimum temperature of the preceding winter was lower than the average, the average number of plants per weevil was higher than the average for the 14 years (table 16). Although the minimum temperature in the winters preceding the 1926 and 1933 crop years was lower than the average, the average number of plants per weevil in May and June was also smaller than the average because large numbers of weevils had entered hibernation the preceding fall. During 7 (1920, 1921, 1922, 1923, 1929, 1932, and 1934) of the 8 remaining years, in which the minimum temperature of the preceding winter was higher than the average for the 14-year period, the average number of plants per weevil in May and June was less than the average. The minimum temperature of the winter preceding the 1931 crop year was higher than the average for the 14 years, but the average number of plants per weevil in May and June was also higher than the average because light rainfall in the summer and fall of 1930 retarded weevil propagation and only a small number entered hibernation.

TABLE 16.—*Effect of minimum winter temperatures and summer precipitation on yield of cotton in treated plots, Madison Parish, La., 1920–34*

Year	Minimum temperature during preceding winter	Average plants per weevil in May and June	Total precipitation June 21 to Aug. 19	0.3 inch or more precipitation from June 21 to Aug. 19	Increase in cotton yield where calcium arsenate treatments were made
	°F.	*Number*	*Inches*	*Days*	*Percent*
1920	18	223	6.92	8	32.8
1921	16	139	9.32	9	44.6
1922	22.5	135	14.62	16	83.9
1923	20	258	7.80	8	20.7
1924	10.5	1,788	1.39	2	1.1
1925	15	5,690	6.57	5	11.7
1926	13	558	8.62	12	68.3
1927	16		8.88	9	33.0
1928	11	2,016	9.05	11	41.2
1929	16	600	5.98	5	11.7
1930	1.8	1,511	1.65	2	9.3
1931	20	2,685	8.53	8	31.8
1932	23	73	7.25	7	45.7
1933	12	67	16.33	12	46.0
1934	20	41	2.52	2	19.5
Average	15.7 [1] (15.6)	[1] 1,127	7.70	7.7	[2] 30.2 [1] (30.1)

[1] 14-year average, 1927 omitted.

[2] See table 2, footnote 1.

During 3 (1924, 1925, and 1930) of the 5 years when the average number of plants per weevil in May and June was higher than the average for the 14 years, the average percentage increase in yield in the treated plots was less than the 14-year average. In 1928 and 1931 the average percentage increase in yield in the treated plots was greater than the average for the 14 years, although the average number of plants per weevil in May and June was higher than the 14-year average

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because the rainfall from June 21 to August 19, inclusive, was above the average. In 6 (1920, 1921, 1922, 1926, 1932, and 1933) of the 9 remaining years when the average number of plants per weevil in May and June was lower than the average, the average percentage increase in yield in the treated plots was greater than the average for the 14 years. Although in 1923, 1929, and 1934, the average number of plants per weevil was less than the average for the 14 years, the average percentage increase in yield in the treated plots was less than the average, because rainfall from June 21 to August 19, inclusive, was less in 1929 and 1934, and because, although very slightly above the average in 1923, it was absent during the early part of the fruiting season (June 24 to July 9).

During 6 (1920, 1921, 1922, 1927, 1931, and 1932) of the 9 years in which the minimum temperature of the preceding winter was higher than the average for the 15 years, the average percentage increase in yield in the treated plots was greater than the average. Although in the crop years of 1923, 1929, and 1934 the minimum temperature of

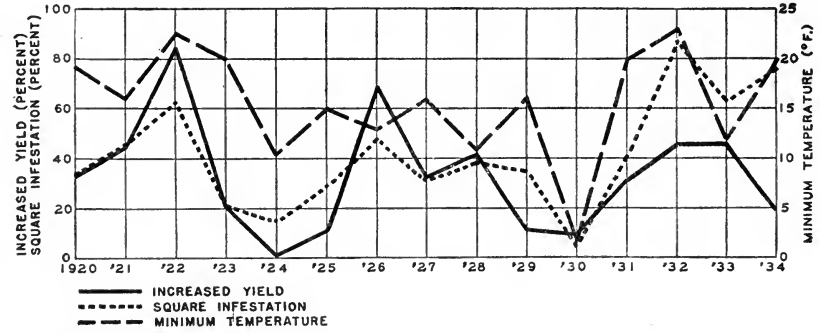

FIGURE 2.—Percentage increase in yield of cotton in plots where bollweevils were controlled as related to square infestation in the untreated plots during the week beginning July 29 and minimum temperature during the preceding winter.

the preceding winter was higher than the average for the 15 years, the average percentage increase in yield in the treated plots was less than the 15-year average because the rainfall from June 21 to August 19, inclusive, was less than average in 1929 and 1934 and, although slightly above the average in 1923, no rain fell during the early part of the fruiting season (June 24 to July 9). In 3 (1924, 1925, and 1930) of the 6 remaining years, in which the minimum temperature of the preceding winter was below the average for the 15 years, the average percentage increase in yield in the treated plots was less than the average. Although in the crop years of 1926, 1928, and 1933 the minimum temperature of the preceding winter was below the average for the 15 years, the average percentage increase in yield in the treated plots was greater than the 15-year average because of the existence of the following conditions: In 1926 the rainfall from June 21 to August 19, inclusive, was above the average, and outbreaks of the cotton flea hopper and the tarnished plant bug destroyed some of the early squares, which resulted in greater weevil damage late in the season; in 1928 the rainfall from June 21 to August 19, inclusive, was above the average, and in 1933 it was more than twice the average. The relation between minimum winter temperatures and the effectiveness of the treatments is shown in figure 2.

EFFECT OF PRECIPITATION ON THE EFFECTIVENESS OF THE TREATMENTS

The figures in table 16 show that the greatest percentage of increase in yield was in 1922, when, from June 21 to August 19, inclusive, the greatest number of days with 0.3 inch or more of precipitation and the second largest amount of precipitation occurred; also, that the smallest percentage of increase was in 1924, when there were only 2 days with 0.3 inch or more of precipitation and the amount of precipitation for that period was least. It will be noted that the number of days with 0.3 inch or more precipitation was the same in 1930 and 1934 as in 1924, and that the amount of precipitation and the percentage of increase were low in each of these years.

In 8 years (1921, 1922, 1923, 1926, 1927, 1928, 1931, and 1933) the total precipitation from June 21 to August 19, inclusive, was greater than the 15-year average, and in 7 of these years the average percentage increase in yield in the treated plots was greater than the average for the 15-year period. In 1923 the total rainfall was just

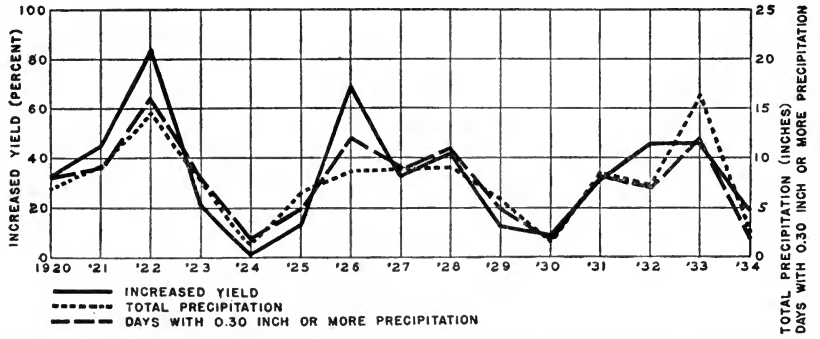

FIGURE 3.—Percentage increase in yield of cotton where bollweevils were controlled as related to the total precipitation and the number of days with 0.3 inch or more precipitation from June 21 to August 19, 1920–34.

above the 15-year average, but the percentage increase in yield was less, because there was no rainfall during the early part of the fruiting season (June 24 to July 9). In 5 (1924, 1925, 1929, 1930, and 1934) of the 7 remaining years, in which the total precipitation from June 21 to August 19, inclusive, was below the average, the average percentage increase in yield in the treated plots was less than the average for the 15-year period. In 1920 and 1932 the rainfall was slightly less than the average, but the weevil population in the field during May and June was much greater than the average.

Figure 3 shows graphically the relation between the precipitation, the number of days with 0.3 inch or more precipitation from June 21 to August 19, and the average percentage increase in yield in the treated plots for each year from 1920 to 1934, inclusive. In general the average percentage increase in yield was closely correlated with the number of days with 0.3 inch or more precipitation and, to a slightly less extent, with the total precipitation from June 21 to August 19.

SUMMARY

Field-plot tests to determine the effectiveness of calcium arsenate treatments for the control of the bollweevil were conducted in Madison Parish, La., over a period of 15 years (1920–34).

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The average annual increase in yield per acre for the plots dusted with calcium arsenate ranged from 10 pounds in 1924 to 742 pounds in 1926, with an average for the 15-year period of 356 pounds, or 30.2 percent.

The difference in the square infestation of the treated and the untreated plots and the increase in yield in the treated plots were greatest in those years when the infestation was the heaviest.

In the years when it was necessary to start treatments early in the season more applications were required than in the years when treatments were started later.

Tests made in 1920 on early, intermediate, and late infestations showed that, although more applications were required for control, greater increases in yields were made in the plots where the infestations began early in the season. With later infestations more cotton was produced than in the early infestations in both treated and untreated plots.

Tests conducted in 1927 on cotton planted at the usual time on unflooded land and planted late after flood waters had receded from the fields indicated that weevils emerging from hibernation concentrated in the older cotton, and that the younger cotton did not become heavily infested until weevils migrated from the older cotton. The concentration of migratory weevils was more pronounced in the western portion of Madison Parish in fields located nearer to unflooded hill land than in the eastern portion of the parish.

Tests conducted in 1928 showed a greater weevil infestation in the untreated plots, and greater increases in yields in the treated plots, in cotton fields where cotton had been grown than in fields where cotton had not been grown in 1927.

Two special control tests in 1932 on cotton, growing in very fertile land, which continued to fruit unusually late in the season showed that the bollweevil could be controlled by calcium arsenate dusting and good gains made when the square infestation was very high and while field migration was in progress.

The number of days with 0.3 inch or more of precipitation from June 21 to August 19, inclusive, showed a greater correlation with the average percentage increase in yield for the treated plots than did the total precipitation during this period or the minimum temperature of the preceding winter.

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COTTON BOLLWEEVIL SURVIVAL AND EMERGENCE IN HIBERNATION CAGES IN LOUISIANA

By R. C. GAINES

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INTRODUCTION

It is fortunate for the American cotton grower that the bollweevil (*Anthonomus grandis* Boh.) is of tropical origin. Its capacity for multiplication during the summer months is so great that cotton production becomes a race between the rate of increase of the weevil and the rapidity of development of the fruit on the cotton plant, and cotton production would be out of the question were it not for the fact that throughout most of the infested districts in the United States a high percentage of the fall population of weevils fails to survive the winter. Consequently, the number of surviving weevils becomes of paramount importance and all possible information on

[1] All hibernation tests from 1915–16 to Jan. 27, 1931, at Tallulah, La., were conducted under the direction of B. R. Coad, and since that time under the direction of the author. The field work was performed by G. L. Garrison, T. C. Barber, R. W. Howe, H. W. Lee, E. S. Tucker, M. T. Young, H. C. Young, R. W. Moreland, F. F. Bondy, T. P. Cassidy, and G. L. Smith, and a number of temporary assistants.

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this critical period in the weevil's life should be obtained. This is especially important because survival is influenced by so many variable factors and also because of the ability of the species to adapt itself to adverse conditions. It will be necessary to extend observations over a long period in order to determine definitely whether the boll-weevil may permanently change its habits as a result of repeatedly adapting itself to conditions in new environments.

Under normal conditions comparatively few factors dominate in the matter of survival but unusual circumstances may cause a factor ordinarily of minor importance to become of prime significance. Some of the best known survival factors may be designated as fall food supply, winter weather, type of shelter, and spring weather. Wet weather during October and November tends to insure a larger emergence of weevils the following spring, as this is favorable to late cotton growth, which, in turn, increases the available quantity of feeding and breeding material for weevils, thus enabling them to enter hibernation in better condition. The date of the first killing frost is also very important. A frost 1 or 2 weeks earlier than usual will greatly reduce the weevil survival, whereas a delaying of the first frost may increase it. Premature defoliation of cotton plants and destruction of the squares and young bolls by the cotton leaf worm (*Alabama argillacea* Hbn.) may affect the condition of weevils entering hibernation. The effect of altitude, latitude, available hibernation quarters, and many other local factors further complicate the problem and add to the difficulties of obtaining reliable and exact information on any one survival factor the significance of which is not open to question.

The importance of a study of bollweevil hibernation has been realized by investigators from the start, and various experiments along this line have been conducted in different localities. These have permitted some general conclusions to be drawn, but the subject is so complicated that the need of a broader series of experiments extending over a longer period has been obvious. Consequently, such a study was inaugurated at the Tallulah, La., field laboratory of the Bureau of Entomology in the fall of 1915 and was continued to 1931. This bulletin presents the results of the study from 1915–16 to 1930–31, with the exception of the winter of 1926–27, when the hibernation cages were destroyed by the overflow of the Mississippi River.

Experiments of the same nature were carried on at 17 cooperating laboratories, the results of which are discussed on page 26.

A study of the influence of the bollweevil on the cotton crop of any particular year must start with the conditions existing during the preceding fall. The factor for first consideration is the number of weevils entering hibernation and their condition at that time. Next in importance is the winter mortality, the result of which is generally expressed as "the percentage of survival." The time of emergence, the proportion of weevils that succeed in infesting cotton plants, and the effect of spring and summer weather on the rate of weevil multiplication must also be considered. It is therefore seen that the amount of weevil damage is the result of all these influencing factors, rather than any one of them. Each of these factors constitutes a separate subject for study, but in this bulletin the discussion is largely confined to only one phase of the problem, that of the factors influ-

encing the percentage of survival. For this reason caution should be exercised in interpreting these results in terms of weevil injury. It is evident that spring population must depend on the percentage of survival of the number entering hibernation the previous fall. In the same way, the initial spring infestation depends on the proportion of these survivors that reach cotton plants and live long enough to produce progeny. The problem is further complicated by rehibernation. It is well known that some weevils in hibernation become active and stir around at times during the winter when there is a warm spell of weather. The number of active weevils increases as the warm weather of spring approaches, and continues to increase until the end of the emergence period. Any study of cage observations clearly shows that many weevils become active before growing cotton appears in the field. Some of these die before squares are available for breeding, but others survive. The above interrelated factors are mentioned at this time chiefly to show how easily incorrect interpretations might be placed upon the result of any one series of tests included in this bulletin.

The effect of low temperatures in killing weevils has been very carefully considered; however, the weevils are not actually exposed to the recorded air temperatures, and the present study is concerned with the resistance of the weevil and its ability to survive different atmospheric temperatures when protected by various types of hibernation shelter, as data of this type have the most practical significance.

PLAN OF EXPERIMENTS

The ideal plan for a study of bollweevil survival would be one in which it would be possible to count the weevils entering hibernation in nature in the fall and those emerging in the spring. This being obviously impossible, experimental conditions as nearly natural as possible were created. This involved the use of cages covered with screen wire; and, as far as possible, all methods were standardized and remained constant throughout the series. However, experience has shown that, even with precautions, it is not always possible to obtain natural conditions and, consequently, results obtained in cages cannot be accepted as valid for natural conditions without verification in the field. The principal merit of the cage tests lies in the fact that they are comparable with one another and with the results obtained by other investigators who used the same methods.

The cages utilized in these experiments were 4 feet square and 4 feet high, inside measurements, strongly constructed of wood, and covered with 16-mesh galvanized screen wire.

The ground on which each cage was placed was carefully leveled, smoothed, and lightly packed. The cage was placed upon the prepared site and securely nailed to stakes driven into the ground at each corner. In addition to this, one or more wires were placed across the top and securely fastened to stakes at some distance from the cage on each side. Several inches of soil was packed around the outside against the bottom of each cage. The hibernation material was placed in the cage, which was then ready to receive the weevils. A general view of the arrangement of these cages is shown in figure 1.

In all experiments the weevils, with the exception of those of series 13, were collected from the cotton fields in the vicinity of Tallulah

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immediately before being placed in the cages. Five hundred weevils were liberated in each cage, except in special studies. They were introduced into the cages in jars. The lids were removed and the jars left open in the cages for 24 hours, after which they were removed. The weevils unable to crawl from the jars were counted and discarded, and subtracting their number from 500 gave the number actually confined in each cage. In this way weaklings and those injured in handling were eliminated.

Since meteorological factors are of the utmost importance in their effect on weevil hibernation, special observations have been made to compare conditions within the cages with those in the open field. Various experiments conducted during several seasons have shown that the screen wire has a marked effect in either raising or lowering the temperature.[2]

FIGURE 1.—General view of hibernation cages.

A series of experiments conducted by Kimball[3] showed that "a plant in any part of the cage should receive on an average at least one-half the total solar and sky radiation, unless it is very close to the south side of the cage, and is considerably south of latitude 40° N." In another series of observations at Tallulah,[2] an anemometer was placed in a cage, and the reading therefrom, compared with that from one in the open air, showed that the air movement within the cage was decreased about 50 percent, a condition that would materially affect both evaporation and humidity. This fact has been verified by other tests which showed decreased evaporation and increased

[2] BARBER, T. C. TEMPERATURE STUDIES UNDER NORMAL AND VARYING CONDITIONS AT TALLULAH, LA., WINTER OF 1915–16. Manuscript reports, January 1917.

[3] KIMBALL, H. H. SHADING EFFECT OF WIRE INSECT CAGES. U. S. Monthly Weather Rev. 44 : 501–506, illus. 1916.

humidity within the cages. It is thus seen that there is a wide difference between conditions within the cages and in the open field.

In connection with these cage tests meteorological records were made. Instruments were installed near the cages and such records as those of maximum and minimum temperatures, humidity, and precipitation were made. This bulletin, however, deals only with those phenomena found to influence the results.

At the outset the tests were arranged in numbered series in such a way that each series afforded a study of one experimental variable. The general procedure was to prepare the cage with the necessary hibernation material and release the weevils at the desired time. Daily records were made of all weevils observed on the top and sides of the cages until activity ceased. The cages were then left undisturbed until March 1, at which time daily observations and removal of emerged weevils were begun.

One important variable was the kind of material provided for hibernation shelter, but for check purposes and in all tests of other factors Spanish-moss (*Tillandsia usneoides* L.) was used as the shelter. In all cases the quantity of hibernation material was uniform and remained so throughout the tests.

The detailed yearly records are omitted because of the space that would be required to present them properly. These records include the dates of cage installations during each fall; weevils found active from the time the cages were installed until all weevils had entered hibernation; daily emergence records for each cage from March 1 until emergence was completed; summary of weevil emergence in each cage and in each series; and temperature, humidity, and rainfall records from the time cages were installed until emergence was completed the following year.

Series 5, 8, and 14 are not discussed in this bulletin as the tests in these cases were for another purpose and not connected with the investigations here considered; and the records for series 2, 3, 7, 10, and 11 were so fragmentary that no definite conclusions could be gleaned from them; they are, however, included in the general summary tables 10, 11, and 13.

SCOPE AND RESULTS OF THE TESTS

RELATION BETWEEN DATE OF INSTALLATION AND WEEVIL SURVIVAL

Series 1 was conducted through 15 seasons, from 1915–16 to 1930–31, to determine the relation between date of weevil installation and survival. Spanish-moss suspended on wires stretched diagonally across near the top of the cage and cotton stalks stripped of fruit and leaves were provided for hibernation shelter in each cage, as illustrated in figure 2, *A*.

The cages were installed at weekly intervals each year, usually starting in the first or second week of September and continuing as long as sufficient weevils were available, the latest being on December 3. Most of the weevils, however, were in cages installed during the period from September 8 to November 11. The earliest cages of this series simulated the effect of an early frost or the early destruction of cotton plants, either of which, by depriving the weevils of food before

any great number of them are in condition to survive the winter, would subject the weevils in the fields to conditions similar to those of the cages. The condensed data from these tests are given in table 1.

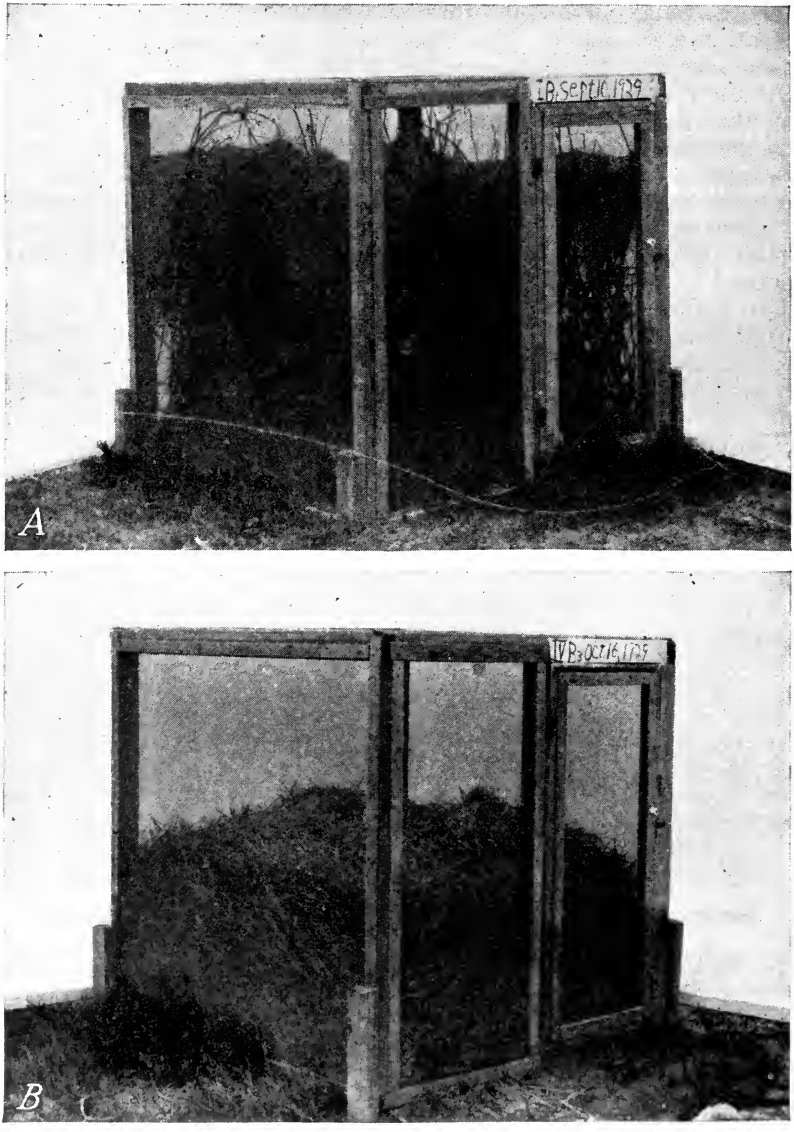

FIGURE 2.—Typical hibernation cages: *A*, Cage in series 1 with Spanish-moss and cotton stalks for shelter; *B*, cage in series 4 with oat straw for shelter.

TABLE 1.—*Relation of date of installation to weevil survival, Tallulah, La., 1915–16 to 1930–31*

[Summary of series 1, Spanish-moss, and cotton stalks for shelter]

Date of installation	Weevils installed	Emergence		Date of installation	Weevils installed	Emergence	
	Number	*Number*	*Percent*		*Number*	*Number*	*Percent*
Sept. 1–7	5,880	0	0.00	Oct. 27–Nov. 4	10,886	318	2.92
Sept. 8–14	8,344	8	.10	Nov. 5–11	6,902	178	2.58
Sept. 15–21	8,103	56	.69	Nov. 12–18	2,954	78	2.64
Sept. 22–28	10,323	77	.75	Nov. 19–25	2,880	17	.59
Sept. 29–Oct. 5	9,663	188	1.95	Nov. 26–Dec. 3	2,659	29	1.09
Oct. 6–12	10,560	107	1.01				
Oct. 13–19	9,322	107	1.15	Total [1]	98,858	1,428	1.44
Oct. 20–26	10,382	265	2.55				

[1] In tables 1 to 10, inclusive, and in table 16, the "total" at the bottom of a "percent" column constitutes a weighted average.

The high average survival of 2.92 percent was in cages installed during the 7 days ending November 4, though there is comparatively little difference in results for the 4 weeks extending from October 20 to November 18. Evidently this period, on the average, was the most favorable time for weevils to enter hibernation. Naturally the lowest survival was in the September installations. The fact that during the different years 12 cages, containing a total of 5,880 weevils, were installed during the first 7 days of September without a single individual surviving is particularly interesting.

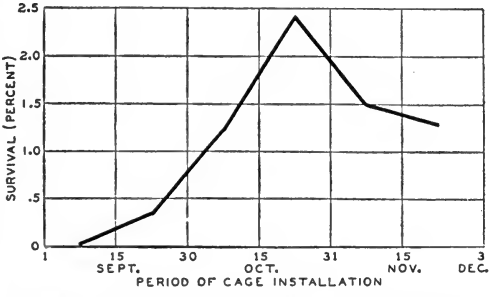

FIGURE 3.—Relation of date of cage installation to bollweevil survival, Tallulah, La., 1915–16 to 1930–31.

To throw further light on this subject, another summary has been prepared, the data of which are presented in table 2 and illustrated graphically in figure 3. In this summary all cages have been included, regardless of other conditions, and are classified solely on the date of installation. This brings in a much wider variety of conditions and greatly increases the number of records involved, thus permitting more representative averages. In this summary the cages have been grouped by approximately 15-day periods. The highest survival occurred in cages installed during the latter half of October and the next highest during the first half of November. It is during these 4 weeks that the first killing frosts, which may cause weevils to enter hibernation under natural conditions, usually occur in this locality. A fairly high survival is also noted in cages installed after November 15. The low survival with early installations is further emphasized in this summary, which shows quite clearly that to derive any benefit from fall stalk destruction in the average year at Tallulah, it would

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be necessary to clean the fields earlier than October 15, and that the maximum benefit could be expected only where stalks were destroyed in September.

TABLE 2.—*Relation of date of installation to weevil survival, Tallulah, La., 1915–16 to 1930–31*

[Summary of all cages and all shelters]

Date of installation	Weevils installed	Emergence		Date of installation	Weevils installed	Emergence	
	Number	*Number*	*Percent*		*Number*	*Number*	*Percent*
Sept. 1–15	61,460	11	0.02	Nov. 1–15	60,689	915	1.51
Sept. 16–30	73,779	261	.35	Nov. 16–Dec. 3	9,444	123	1.30
Oct. 1–15	125,325	1,531	1.22				
Oct. 16–31	99,667	2,405	2.41	Total	430,364	5,246	1.22

SURVIVAL OF UNFED WEEVILS

Series 2 of the tests was started in 1915–16 and repeated in 1916–17 to test the hibernating ability of weevils that had been deprived of all food since emergence as adults. The weevils used were reared in the laboratory from infested squares collected in the field and were released in the cages without having had opportunity to feed. In the cage used as a check, field-collected weevils were released. Spanish-moss suspended in the cages afforded the hibernation shelter. This was one of the series of tests that afforded no definite results.

SURVIVAL OF UNMATED FEMALES

Series 3 was undertaken in order to investigate the ability of unfertilized females to survive the winter. The series included cages containing reared female weevils that had had no opportunity to mate after reaching maturity, and, for comparison, other cages containing field-collected individuals. Spanish-moss was provided as a shelter. This series was conducted for only one winter, that of 1915–16 , and, as with series 2, offered no conclusive results.

COMPARISON OF VARIOUS SHELTER MATERIALS

OAT STRAW AS SHELTER

Series 4 was conducted for 15 seasons, from 1915–16 to 1930–31, to study weevil hibernation in oat straw and to compare this shelter material with Spanish-moss. Two cages, one with each material, were installed on the same day at biweekly intervals during the fall of each year. A cage with oat straw is shown in figure 2, *B*, and a check cage with Spanish-moss, such as was used with all the tests, is shown in figure 4, *A*.

The results of this test are given in table 3. In the final average there was only a slight difference between the protection afforded by oat straw and that afforded by Spanish-moss, the survival in the Spanish-moss being 1.60 percent and in the oat straw 1.24 percent.

TABLE 3.—*Comparison of Spanish-moss and oat straw as bollweevil shelter, Tallulah, La., 1915–16 to 1930–31*

[Summary of series 4]

Date of installation	Spanish-moss shelter			Oat-straw shelter		
	Weevils installed	Emergence		Weevils installed	Emergence	
	Number	*Number*	*Percent*	*Number*	*Number*	*Percent*
Sept. 14–19	5,213	10	0.19	5,461	3	0.05
Sept. 25–Oct. 6	6,783	52	.77	6,668	11	.16
Oct. 11–18	6,315	133	2.11	6,176	85	1.38
Oct. 25–Nov. 6	6,811	206	3.02	6,677	210	3.15
Total	25,122	401	1.60	24,982	309	1.24

TREE STUMP AS SHELTER

A comparison of Spanish-moss and a tree stump as weevil shelters was afforded in the tests of series 6, conducted during 1915–16, 1916–17, and 1918–19. Field observations have called attention to the danger of stumps as weevil shelter because they are usually surrounded with masses of weeds and grass that are allowed to remain over the winter. The preceding test with oat straw, a somewhat similar material, showed the place of the material as an aid to successful hibernation.

The purpose of this series was to study the possibilities of the bare stump as a protection for hibernating weevils. On each date of installation a cage was placed over a stump cleared of grass and weeds, and 500 weevils were introduced, while the same number were released in a check cage containing Spanish-moss. From table 4 it is seen that while more than twice as many weevils emerged from the moss as from the stump, the survival in the stump cages was still high enough to be of importance.

TABLE 4.—*Comparison of Spanish-moss and stump as bollweevil shelter, Tallulah, La., 1915–16, 1916–17, and 1918–19*

[Summary of series 6]

Date of installation	Spanish-moss shelter			Stump shelter		
	Weevils installed	Emergence		Weevils installed	Emergence	
	Number	*Number*	*Percent*	*Number*	*Number*	*Percent*
Oct. 20	500	1	0.20	500	1	0.20
Oct. 28	500	5	1.00	500	0	.00
Nov. 2	----------	----------	----------	500	10	2.00
Nov. 3	500	22	4.40	----------	----------	----------
Total	1,500	28	1.87	1,500	11	.73

Under such circumstances the practice of piling weeds or grass around field stumps in the winter and burning them is certainly to be recommended, not only as a means of getting rid of the stumps and trash, but also as a weevil-control measure.

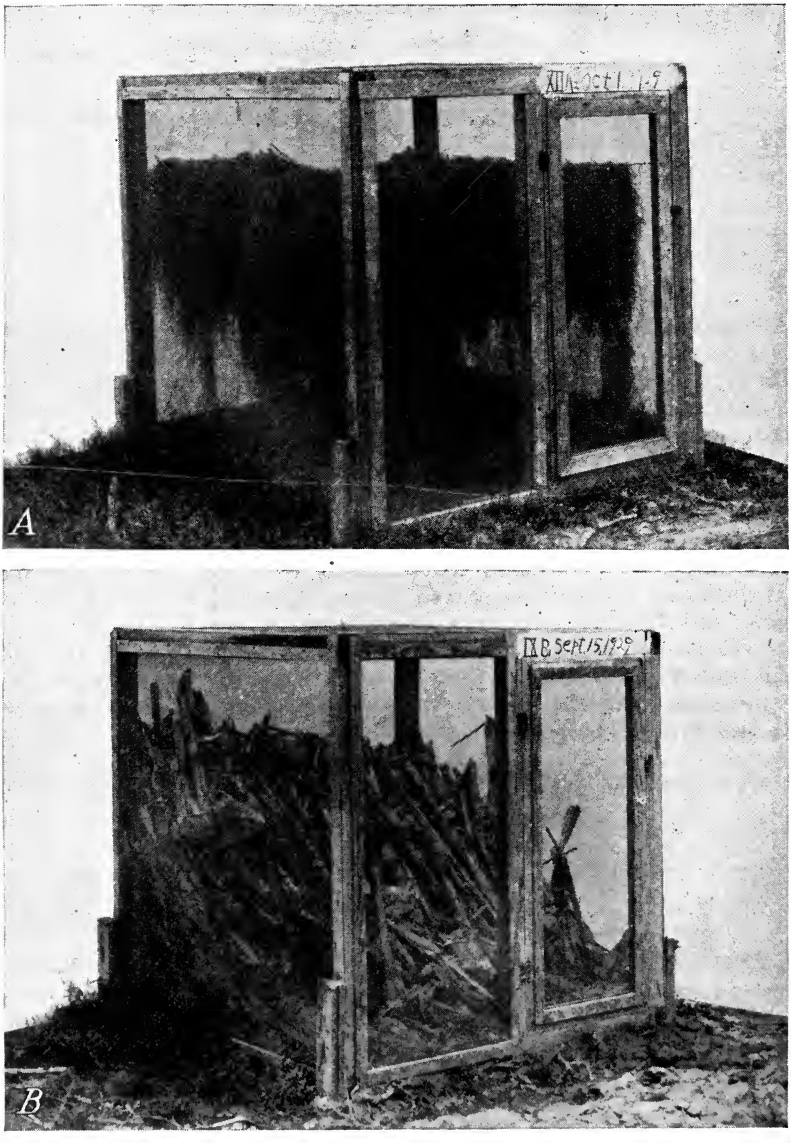

FIGURE 4.—Hibernation cages: *A*, Typical check cage with Spanish-moss for shelter; *B*, a cage in series 9 with cornstalks for shelter.

CORNSTALKS AND COTTON STALKS AS SHELTERS

A comparison of weevil survival in shelters of cornstalks, cotton stalks, and Spanish-moss was provided in series 9, which was carried on for 14 seasons beginning with 1916–17. Three cages, each containing one of these materials, were installed at regular biweekly intervals throughout the fall of each year. The test cages were partly filled with cornstalks (fig. 4, *B*), or cotton stalks from which the foliage and fruit had been removed (fig. 5, *A*). The Spanish-moss cages were prepared in the usual manner of the check cages. Table 5 shows that the cornstalks proved to be the superior shelter, with the moss ranking second and the cotton stalks third.

TABLE 5.—*Comparison of Spanish-moss, cornstalks, and cotton stalks as boll-weevil shelter, Tallulah, La., 1916–17 to 1930–31*

[Summary of series 9]

Date of installation	Spanish-moss			Cornstalks			Cotton stalks		
	Weevils installed	Emergence		Weevils installed	Emergence		Weevils installed	Emergence	
	Number	*Number*	*Percent*	*Number*	*Number*	*Percent*	*Number*	*Number*	*Percent*
Sept. 2–9							1,000	0	0.00
Sept. 12–21	5,270	10	0.19	5,198	8	0.15	5,709	3	.05
Sept. 24–Oct. 2	6,795	40	.59	6,696	48	.72	7,194	13	.18
Oct. 6–19	6,234	93	1.49	6,189	96	1.55	6,786	55	.81
Oct. 22–Nov. 6	6,341	165	2.60	5,728	323	5.64	7,299	138	1.89
Nov. 13							500	5	1.00
Nov. 22							500	2	.40
Total	24,640	308	1.25	23,811	475	1.99	28,988	216	[1].77

[1] This average is based only on the 4 periods that were covered by the averages obtained with Spanish-moss and cornstalk shelters. Including all 7 periods, the average is 0.75.

MIXTURE OF CORNSTALKS, STRAW, AND SPANISH-MOSS AS SHELTER

Series 11 was conducted for only two winters, 1916–17 and 1918–19. A mixture of oat straw, Spanish-moss, and cornstalks was compared with Spanish-moss alone as a hibernation shelter for the cotton boll-weevil. There was no emergence from the stalk-straw-moss cages, but as emergence was generally low in those two seasons the results cannot be considered conclusive.

HIBERNATION ON BARE GROUND

One cage with Spanish-moss and one with no shelter whatever were installed at biweekly intervals during the fall of 12 years (1918 to 1930), 500 weevils being used in each cage. The results are summarized in table 6, where it is shown that 1.83 percent of the weevils survived in the check cages with moss, whereas only 0.09 percent survived in the cages with no shelter. Even this percentage of survival on the bare ground is rather surprising.

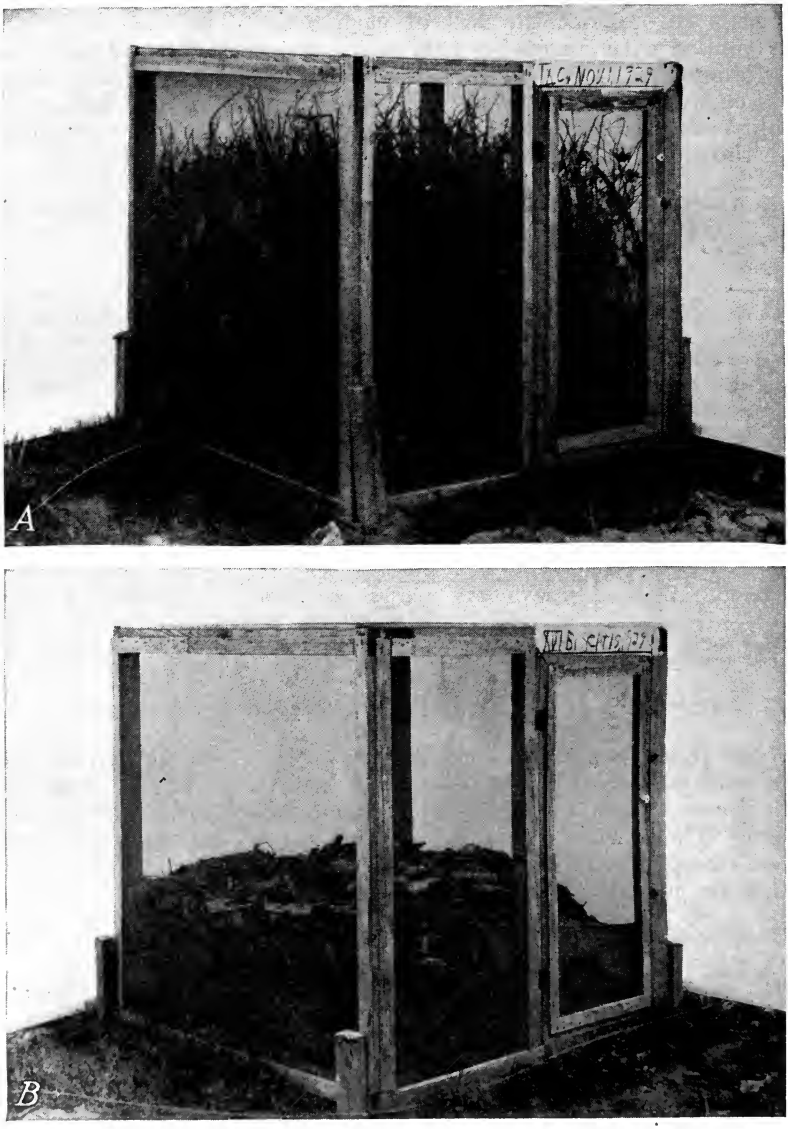

FIGURE 5.—Hibernation cages: *A*, A cage in series 9 with cotton stalks for shelter; *B*, a cage in series 16 containing sawmill debris consisting of chips and pieces of board and bark.

TABLE 6.—*Comparison of bollweevil survival in Spanish-moss and on bare ground, Tallulah, La., 1918–19 to 1930–31*

[Summary of series 15]

Date of installation	Spanish-moss			Bare ground		
	Weevils installed	Emergence		Weevils installed	Emergence	
	Number	*Number*	*Percent*	*Number*	*Number*	*Percent*
Sept. 14–19	5,021	18	0.36	5,224	1	0.02
Sept. 29–Oct. 2	5,263	87	1.65	5,120	1	.02
Oct. 13–18	5,299	112	2.11	5,373	9	.17
Oct. 25–Nov. 6	6,369	184	2.89	6,338	8	.13
Total	21,952	401	1.83	22,055	19	.09

SAWMILL DEBRIS AS SHELTER

Over a period of 11 winters, from 1919–20 to 1930–31 (except 1926–27), series 16 was conducted to compare the protection afforded by sawmill debris such as chips and pieces of board and bark with Spanish-moss. The cages (fig. 5, *B*) were installed at biweekly intervals from September 14 to November 6, as shown in table 7, with an average survival in the debris cages of 1.36 percent as compared with a survival of 1.74 percent in the cages with Spanish-moss.

TABLE 7.—*Comparison of Spanish-moss and sawmill debris as bollweevil shelter, Tallulah, La., 1919–20 to 1930–31*

[Summary of series 16]

Date of installation	Spanish-moss			Boards, chips, etc.		
	Weevils installed	Emergence		Weevils installed	Emergence	
	Number	*Number*	*Percent*	*Number*	*Number*	*Percent*
Sept. 14–19	5,154	18	0.35	5,122	0	0.00
Sept. 29–Oct. 2	5,314	67	1.26	5,244	28	.53
Oct. 13–18	4,848	67	1.38	4,885	88	1.80
Oct. 29–Nov. 6	5,319	207	3.89	5,283	163	3.09
Total	20,635	359	1.74	20,534	279	1.36

EFFECT OF COVERING CAGES

Series 12 was conducted for 13 seasons, beginning with 1917–18, to study the effect of roofing the cages with boards and covering the sides of some of these with boards and of others with canvas (fig. 6, *A*). Spanish-moss was used as the hibernation material. Three cages, 1 altogether open as a check cage, 1 covered on the sides and top with boards, and 1 roofed with boards and having canvas sides, were installed every 2 weeks during the fall of each year.

The cages sided with boards were entirely rainproof, but a little moisture could enter the cages enclosed with canvas. The series was designed to furnish conditions as similar as possible to those that would be found by weevils passing the winter within or under

FIGURE 6.—Hibernation cages: *A*, covered cages used in series 12 showing a cage with canvas sides and one with board sides; *B*, cages protected by standing timber, series 18, containing Spanish-moss and cotton stalks for shelter.

buildings, sheds, gins, etc., where, in addition to some protection from cold, the insects would also escape the effects of rainfall. Table 8 shows that the emergence from the uncovered cages was roughly three times that from the covered ones, with no significant differences between the survival in the two types of covered cages.

TABLE 8.—*Bollweevil survival in Spanish-moss shelter as affected by covering of cage, Tallulah, La., 1917–18 to 1930–31*

[Summary of series 12]

Date of installation	Uncovered wire cage			Cage roofed and sided with boards			Cage roofed with boards and sided with canvas		
	Weevils installed	Emergence		Weevils installed	Emergence		Weevils installed	Emergence	
	Number	*Number*	*Percent*	*Number*	*Number*	*Percent*	*Number*	*Number*	*Percent*
Sept. 14–19	5,159	13	0.25	5,246	3	0.06	5,192	1	0.02
Sept. 29–Oct. 6	5,726	38	.66	5,878	5	.09	5,871	22	.37
Oct. 13–20	5,326	76	1.43	5,294	23	.43	5,228	27	.52
Oct. 23–Nov. 6	5,812	175	3.01	5,900	82	1.39	5,752	44	.76
Total	22,023	302	1.37	22,318	113	.51	22,043	94	.43

EFFECT OF STANDING TIMBER

Series 18 was conducted for 5 seasons between 1925–26 and 1930–31 in order to study the protection afforded by standing timber to the hibernating cotton bollweevils. Throughout the fall, cages containing Spanish-moss and cotton stalks were installed at weekly intervals. These cages were in every respect like those of series 1, with which they are compared, except that they were located in woodland, as shown in figure 6, *B*. Table 9 shows that the average survival in the cages in the woods was 0.57 percent as compared with that of 0.88 percent in the cages of series 1 in the open field for the same years.

TABLE 9.—*Comparison of bollweevil survival in cages in woods and in open field (Spanish-moss plus cotton stalks as shelter), Tallulah, La., 1925–26 to 1930–31*

[Summary of series 18]

Date of installation	Cages in woods			Cages in open field			Difference [1]
	Weevils installed	Emergence		Weevils installed	Emergence		
	Number	*Number*	*Percent*	*Number*	*Number*	*Percent*	*Percent*
Sept. 1–7	2,479	1	0.04	3,453	0	0.00	−0.04
Sept. 8–14	2,465	0	.00	3,452	2	.06	+.06
Sept. 15–21	2,467	2	.08	3,407	6	.18	+.10
Sept. 22–28	2,461	5	.20	3,472	25	.72	+.52
Sept. 29–Oct. 5	2,462	6	.24	3,381	21	.62	+.38
Oct. 6–12	2,415	18	.75	3,385	23	.68	−.07
Oct. 13–19	2,438	16	.66	3,423	51	1.49	+.83
Oct. 20–26	2,447	29	1.19	3,450	53	1.54	+.35
Oct. 27–Nov. 4	2,952	45	1.52	4,458	59	1.32	−.20
Nov. 5–11	2,399	18	.75	3,424	67	1.96	+1.21
Nov. 12–18	960	16	1.67	977	36	3.68	+2.01
Nov. 19–25	970	3	.31	1,500	2	.13	−.18
Nov. 26–Dec. 3	949	0	.00	1,833	2	.11	+.11
Total	27,864	159	.57	39,615	347	.88	+.31

[1] Plus (+) denotes increased emergence in cages in open field, and minus (−) decreased emergence in those cages.

GENERAL COMPARISON OF ALL HIBERNATION MATERIALS

The comparisons given show the results of the special tests with each kind of shelter, and, in order to afford a more general comparison, additional summaries have been prepared which include all cages classified by shelter materials regardless of other conditions. In table 10 is presented a summary of the percentage of survival in different materials, while the rate of emergence is given in table 11 to show any effect these materials may have on the time when the weevils leave hibernation. From table 10 it is seen that cornstalks gave the highest average survival of any type of shelter, with Spanish-moss ranking second, and that the lowest survival was recorded in the cages with bare ground. The fact that no weevils emerged in series 11 is not considered significant, as that series was conducted for only 2 years, and weevil survival in those years was low.

TABLE 10.—*General summary of bollweevil survival in all cages classified by hibernation shelter, Tallulah, La., 1915–16 to 1930–31*

Nature of shelter and series	Weevils installed	Emergence	
	Number	*Number*	*Percent*
Cornstalks (series 9)	23, 811	475	1. 99
Spanish-moss (series, 2, 3, 4, 6, 7, 9, 10, 11, 12, 13, 15, 16, 17)	129, 026	2, 143	1. 66
Spanish-moss, plus cotton stalks (series 1)	98, 858	1, 428	1. 44
Sawmill debris (series 16)	20, 534	279	1. 36
Oat straw (series 4)	24, 982	309	1. 24
Cotton stalks (series 9)	28, 988	216	. 75
Stump (series 6)	1, 500	11	. 73
Spanish-moss, plus cotton stalks (in woods, series 18)	27, 864	159	. 57
Spanish-moss, and cage covered with boards (series 12)	22, 318	113	. 51
Spanish-moss, and cage covered with canvas (series 12)	22, 043	94	. 43
Bare ground (series 15)	22, 055	19	. 09
Spanish-moss, oat straw, and cornstalks (series 11)	8, 385	0	. 00
Total	430, 364	5, 246	1. 22

TABLE 11.—*Summary of rate of weevil emergence*[1] *from various shelters used in hibernation cages, Tallulah, La., 1915–16 to 1930–31*

Nature of shelter	Weevils installed	Cumulative emergence by months									
		March		March and April		March, April, and May		March, April, May, and June		March, April, May, June, and July	
	Number	*Number*	*Percent*	*Number*	*Percent*	*Number*	*Percent*	*Number*	*Percent*	*Number*	*Percent*
Stump	1, 500	5	45. 5	10	90. 9	11	100. 0	------	------	------	------
Cotton stalks	28, 988	55	25. 5	129	59. 7	211	97. 7	216	100. 0	------	------
Oat straw	24, 982	100	32. 4	188	60. 8	300	97. 1	309	100. 0	------	------
Sawmill debris	20, 534	113	40. 5	190	68. 1	263	94. 3	279	100. 0	------	------
Spanish-moss and cage covered with canvas	22, 043	27	28. 7	60	63. 8	88	93. 6	94	100. 0	------	------
Bare ground	22, 055	7	36. 8	14	73. 7	17	89. 5	19	100. 0	------	------
Cornstalks	23, 811	55	11. 6	182	38. 3	421	88. 6	475	100. 0	------	------
Spanish-moss, plus cotton stalks	98, 858	166	11. 6	453	31. 7	1, 037	72. 6	1, 426	99. 9	1, 428	100. 0
Spanish-moss	129, 026	247	11. 5	673	31. 4	1, 562	72. 9	2, 133	99. 5	2, 143	100. 0
Spanish-moss and cage covered with boards	22, 318	32	28. 3	68	60. 2	96	85. 0	112	99. 1	113	100. 0
Spanish-moss, plus cotton stalks (in woods)	27, 864	18	11. 3	58	36. 5	101	63. 5	156	98. 1	159	100. 0

[1] Expressed as the percentage of the number that emerged as shown in table 10: not, therefore, comparable with the percentages of emergence given in preceding tables.

EFFECT OF SIZE OF CAGE

Series 7 was carried on for only one season, the winter of 1915–16, for the purpose of determining the effect on weevil survival of increasing the size of the cage to 8 feet long by 5 feet wide and 6 feet high as compared with the standard cage 4 by 4 by 4 feet. No conclusive difference could be detected.

EFFECT OF VARIOUS NUMBERS OF WEEVILS PER CAGE

Series 17 was begun in 1923–24 and conducted for 7 years to determine the effect of the number of weevils in a cage on the survival. In the regular tests the standard number of 500 weevils was used mainly because previous investigators had generally used that number, and it was highly desirable to follow their methods as far as possible so that results could be compared. It was felt, however, that this number might be excessive for the type of cage in use, and the overcrowding might prevent some of the weevils from receiving the best shelter and thus result in an increased mortality.

Consequently in series 17, populations of approximately 25, 50, 100, 250, 350, and 500 weevils were used; a complete series being started on October 10 and 20 of each year. Spanish-moss was furnished for shelter. Table 12 shows that the highest survivals occurred in the cages with approximately 50, 100, and 250 weevils per cage.

TABLE 12.—*Survival of bollweevils as affected by varying the numbers per cage (Spanish-moss used as weevil shelter), Tallulah, La., 1923–24 to 1930–31*

[Summary of series 17]

Date of installation	Weevils installed per cage (approximate)	Total weevils installed	Emergence	
	Number	*Number*	*Number*	*Percent*
Oct. 10 and 20	25	334	3	0.90
	50	671	14	2.09
	100	1,347	26	1.93
	250	3,321	66	1.99
	350	4,829	66	1.37
	500	6,884	103	1.50

COMPARISON OF WEEVILS FROM DIFFERENT SOURCES

Series 13 was conducted during the seasons of 1916–17 and 1917–18 for the purpose of ascertaining whether weevils from various localities differed in their resistance to winter weather. It had been suggested that weevils native to a more southerly district might be less resistant to winter conditions than those occurring in a more northerly district. Consequently, two additional localities were selected; one at Opelousas, La., about 125 miles south of Tallulah, and the other at Scott, Miss., about 100 miles north of Tallulah. Field-collected weevils were gathered at each of these points and also at Tallulah. Cage installations were made at each point with weevils from all three lots. At each point the complete series enabled a comparison to be made between native weevils and those from the other two points.

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The results for the most part were somewhat erratic, and about the only consistent one was the fact that native weevils proved to be more resistant than those that had undergone shipment, regardless of the source. Consequently, it was apparent that the hardships of transportation overshadowed any other differences that might have existed.

GENERAL SUMMARY OF SURVIVAL AND EMERGENCE

All cage tests have been brought together by years in table 13 to show average percentage of survival, rate of emergence, and emergence period. From this table it is seen that a total of 430,364 weevils were installed in all cages under various conditions during all years. Of these 5,246 or 1.22 percent, emerged. Of the total number of weevils surviving, 15.7 percent emerged in March, 22.9 percent in April, 39.7 percent in May, 21.4 percent in June, and 0.3 percent in July. In other words, emergence was 38.6 percent complete at the end of April, 78.3 percent complete at the end of May, and 99.7 percent complete at the end of June. The average cumulative bollweevil emergence is shown graphically in figure 7. The emergence period for the various years ranged from 47 to 127 days, with a weighted average of 117 days. The extremely short periods were during the years of very low survival. During 3 of the 15 years emergence was recorded on March 1 and was recorded during March in 14 of the 15 years. The date of completion of emergence ranged from April 27 to July 7. Emergence extended into June, however, in all of the years except 3; and since only 11 weevils emerged during those 3 years, this number is too small to be significant. Extension of the period of emergence into June is therefore probably of general occurrence. Emergence extended into July in only 4 years.

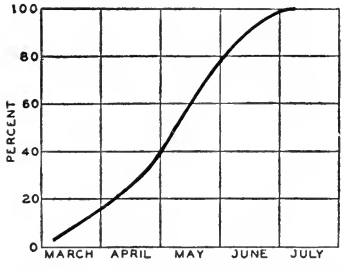

FIGURE 7.—Cumulative frequency curve; percentage of bollweevil emergence classified according to time of emergence.

TABLE 13.—*General summary of weevil emergence by months and periods of emergence, Tallulah, La., 1915–16 to 1930–31*

Year	Weevils installed	Period of emergence		Number of weevils and percent of total emergence by months										Total emergence		Period of emergence
		First date	Last date	March		April		May		June		July				
	Number			*Number*	*Percent*	*Number*	*Percent*	*Number*	*Percent*	*Number*	*Percent*	*Number*	*Percent*	*Number*	*Percent*	*Days*
1915–16	13,100	Mar. 10	June 23	116	14.4	127	15.8	479	59.6	82	10.2	0	0.0	804	6.14	106
1916–17	21,669	Mar. 15	June 6	18	50.0	9	25.0	3	8.3	6	16.7	0	.0	36	.17	84
1917–18	9,500	Mar. 21	May 22	2	40.0	1	20.0	2	40.0	0	.0	0	.0	5	.05	63
1918–19	19,945	Apr. 2	June 10	0	.0	11	17.7	44	71.0	7	11.3	0	.0	62	.31	70
1919–20	27,341	Mar. 30	June 21	9	6.8	64	48.5	57	43.2	2	1.5	0	.0	132	.48	84
1920–21	26,286	Mar. 1	June 6	165	45.6	85	23.5	108	29.8	4	1.1	0	.0	362	1.38	98
1921–22	28,536	Mar. 14	July 7	173	14.4	264	21.9	466	38.7	298	24.8	2	.2	1,203	4.22	116
1922–23	34,375	Mar. 3	July 5	58	10.6	139	25.4	189	34.5	158	28.8	4	.7	548	1.59	125
1923–24	30,648	Mar. 4	June 14	3	8.6	14	40.0	14	40.0	4	11.4	0	.0	35	.11	103
1924–25	33,565	Mar. 12	Apr. 27	2	50.0	2	50.0	0	.0	0	.0	0	.0	4	.01	47
1925–26	40,376	Mar. 1	June 8	7	31.8	11	50.0	3	13.6	1	4.6	0	.0	22	.05	100
1927–28	46,384	Mar. 12	June 11	4	36.4	2	18.2	2	18.2	3	27.2	0	.0	11	.02	92
1928–29	33,999	Mar. 2	July 6	92	34.8	59	22.4	88	33.3	24	9.1	1	.4	264	.78	127
1929–30	31,786	Mar. 1	May 22	1	50.0	0	.0	1	50.0	0	.0	0	.0	2	.01	83
1930–31	32,854	Mar. 3	July 7	175	10.0	412	23.5	626	35.6	534	30.4	9	.5	1,756	5.34	127
Summary of all years	430,364	Mar. 1	July 7	825	15.7	1,200	22.9	2,082	39.7	1,123	21.4	16	.3	5,246	1.22	[1] 117

[1] Weighted average.

From the foregoing it is seen that the experimental procedures were standardized, except for certain variables which may be grouped in the following nine classifications: Varying dates of installation; weevils that had been fed versus unfed weevils; fertilized females versus unfertilized ones; comparisons of various shelter materials; different sizes of cage; covered cages versus uncovered ones; weevils from different localities; varying numbers of weevils per cage; and open-field location versus timber. Of these the dates of installation and various shelter materials were the most important variables and received the most attention.

RELATION BETWEEN WINTER WEATHER AND PERCENTAGE OF SURVIVAL

The relation between winter weather and percentage of survival, as shown in table 14, is evident; however, in analyzing the results of these tests every effort has been made to isolate those factors which showed the closest correlation with survival. All meteorological observations available have been summarized and compared with the figures representing survival. For the sake of brevity, a discussion of fruitless efforts is not included, but it may be mentioned that no correlations were found between the records of survival and those of maximum temperature, mean temperature, humidity, or rainfall; and it was not until minimum temperatures alone were considered that significant correlations were encountered.

TABLE 14.—*Relation between minimum temperatures and percentage of weevil survival, Tallulah, La., 1915–16 to 1930–31*

Year	Days temperature September to March fell below—						Minimum temperature	Weevil survival
	32° F.	30° F.	24° F.	22° F.	20° F.	18° F.		
	Number	*Number*	*Number*	*Number*	*Number*	*Number*	*° F.*	*Percent*
1929–30	44	33	15	13	11	9	1.8	0.01
1924–25	49	37	15	8	4	2	15	.01
1927–28	43	34	15	10	10	6	11	.02
1925–26	47	31	11	6	3	2	13	.05
1917–18	60	51	28	21	14	10	1	.05
1923–24	51	34	8	7	5	3	10.5	.11
1916–17	45	33	19	11	5	4	16	.17
1918–19	45	30	13	9	4	4	9	.31
1919–20	39	29	12	5	2	0	18	.48
1928–29	43	34	15	12	7	3	16	.78
1920–21	35	24	6	3	1	1	16	1.38
1922–23	26	23	7	3	0	0	20	1.59
1921–22	30	16	3	0	0	0	22.5	4.22
1930–31	37	28	6	1	0	0	20	5.34
1915–16	32	21	9	4	0	0	20	6.14

The coefficients of correlation between the number of times the temperature fell below a certain number of degrees Fahrenheit and the percentage of weevil survival are given in table 15. It will be noted that all coefficients, except one, between these two variables are significant, and that the greatest correlation, which was -0.64 ± 0.10, was shown between the number of times the temperature fell below 32° and 30° F. and the percentage of weevil survival. Correlation is also shown between the minimum temperature for the winter and survival, the coefficient being $+0.63 \pm 0.10$. To determine what particular minimum temperatures cause the highest mor-

tality of weevils in hibernation, coefficients of correlation were computed between the number of times a given temperature prevailed and the percentage of weevil survival. These are also given in table 15. It will be noted that only 2 of these coefficients are significant, namely, the number of times the temperature ranged from 18° to 20°, and from 1° to 17°. In other words, the results indicate that the occurrence of temperatures of 20°, or lower, are accompanied by the lowest survival. Winter minimum temperatures taken by themselves seem to explain only in part the winter mortality of weevils. Undoubtedly, all such factors as the temperatures preceding low temperatures, the duration of extremely cold spells, the rate of change in temperature, the frequency of temperature changes, whether or not rain precedes low temperatures, and the presence of sleet or snow, have an influence on weevil mortality.

TABLE 15.—*Percentage of bollweevil survival correlated with winter temperatures at Tallulah, La., 1915–16 to 1930–31*

Percentage of weevil survival correlated with—			
Days temperature fell below the following degrees:		Days temperature fell to the following degrees:	
° F.	*Correlation coefficient*	° F.	*Correlation coefficient*
36	−0.33±0.16	35, 34, and 33	+0.24±0.16
32	−.64± .10	32, 31, and 30	−.06± .17
30	−.64± .10	29, 28, and 27	−.39± .15
24	−.57± .12	26, 25, and 24	+.10± .17
22	−.62± .11	23, 22, and 21	−.06± .17
20	−.62± .11	20, 19, and 18	−.57± .12
18	−.57± .12	17 to 1	−.57± .12
Minimum temperature for winter	+.63± .10		

INFLUENCE OF TEMPERATURE ON WEEVIL EMERGENCE

Before discussing the influence of temperature on weevil emergence at Tallulah, it will probably be well to review the findings of a few other investigators.

Hunter and Hinds [4] state:

Emergence depends largely, as has already been shown, upon the mean average temperature prevailing. The presence of food does not seem to affect it. In the season of 1903 for one month preceding the emergence of weevils at Victoria [Texas] the mean average temperature was 65.4° F. For the first two weeks of April it averaged 68.4° F. Weevils left their winter quarters from the middle to the last of April. While the mean average temperature for May was nearly 3° lower than the temperature prevailing at the time of emergence, weevils remained actively at work in the fields. In the fall also weevils remained at work at a lower temperature than that which seems to be necessary to draw them from their winter quarters. The reason for this fact is not apparent, but it is certain that once having left hibernation weevils will remain active at considerably lower temperatures.

According to Hunter and Pierce: [5]

The number of weevils emerging under 57° F. is very small indeed. From that point the emergence increases with the increase in temperature until a

[4] HUNTER, W. D., and HINDS, W. E. THE MEXICAN COTTON BOLL WEEVIL. U. S. Dept. Agr., Bur. Ent. Bull. 51, 181 pp., illus. 1905. (See pp. 106–107.)

[5] HUNTER, W. D., and PIERCE, W. D. THE MEXICAN COTTON-BOLL WEEVIL: A SUMMARY OF THE INVESTIGATIONS OF THIS INSECT UP TO DECEMBER 31, 1911. U. S. Dept. Agr., Bur. Ent. Bull. 114, 188 pp., illus. 1912. (62d Cong., 2d sess., Sen. Doc. 305.) (See p. 108.)

majority of the weevils have emerged. Most weevils have been found to leave their winter quarters during a temperature averaging between 64° and 78° F. At Keatchie 75 per cent and at Dallas 96 per cent of the total emergence took place between these limits. At Dallas the largest emergence occurred between temperatures of 64° and 68° F., while at Keatchie the largest emergence occurred between 74° and 78° F.

Hinds and Yothers[6] state:

The more complete records now at hand indicate that emergence may take place whenever the mean average temperature exceeds 55° F. It is certain that weevils may be active at a temperature considerably lower than this, but the records do not indicate that there is a general emergence from hibernation at a lower temperature.

Weevil emergence at Tallulah began between March 1 and 15 in 12 of the 15 years covered by this study; on March 21 in 1 year; on March 30 in 1 year; and on April 2 in 1 year. On the days that the first weevils emerged the maximum temperature ranged from 55° to 84° F., the average being 73.8°; however, the maximum was less than 72° in only 3 years. On the day preceding the first weevil emergence of the year the maximum temperature ranged from 44° to 84°, with an average of 71°. The maximum was less than 70° in only 4 of these years.

In 8 of the years the mean temperature was from 60° to 69.5° F. on the day the first weevils emerged, and in each case this date had been preceded by days with mean temperatures of 60° or higher. In the remaining 7 years the mean temperature was from 43.5° to 59.5° on the day the first weevils emerged, but during 5 of these years the mean temperature was 60° or above on 1 or more days prior to emergence. These records indicate that few weevils emerge from hibernation in cages when the maximum temperatures are below 70° and mean temperatures below 60°, which temperatures are usually reached in the vicinity of Tallulah during the last few days of February or the first few days of March.

After weevils begin to emerge there is a definite positive correlation between emergence and both maximum and mean temperatures until the peak of emergence is reached, which is usually during May. After the peak is reached no further correlation exists between these factors.

RELATION BETWEEN PRECIPITATION AND WEEVIL EMERGENCE

During the 15 years under consideration, from the beginning to the end of weevil-emergence periods there was a total of 1,425 days, and on 715, or 50.2 percent of these days, 1 or more weevils emerged. A total of 5,246 weevils emerged in all cages, or an average of 3.68 weevils per day for the total of the emergence periods. Rainfall of 0.01 inch or more was recorded on 372 of the 1,425 days in the total emergence periods. A total of 1,330 weevils emerged on the days on which rain occurred, or an average of 3.58 weevils per day. On 189 days on which rain occurred no weevils emerged in any of the cages.

For an average of all years, 25.4 percent of the total surviving weevils emerged on days on which rain was recorded, 12.2 percent on

[6] HINDS, W. E., and YOTHERS, W. W. HIBERNATION OF THE MEXICAN COTTON BOLL WEEVIL. U. S. Dept. Agr., Bur. Ent. Bull. 77, 106 pp., illus. 1909. (See pp. 68–69.)

the first day following rain, 10 percent on the second day, 8.5 percent on the third day, 6.7 percent on the fourth day, 6.4 percent on the fifth day, 7.1 percent on the sixth day, 5.8 percent on the seventh day, and so on, with percentages decreasing to the twenty-seventh day. A total of 82.1 percent of the surviving weevils emerged on the days on which rain was recorded and within 7 days after rain occurred, and the remaining 17.9 percent emerged from the eighth to the twenty-seventh day, inclusive, after rain occurred. A total of 37.6 percent emerged on days of rain and on the first day following.

In cases of several days of consecutive rainfall the weevils emerging on such days were recorded as emerging on a day of rainfall even though the same date could have been considered as a day following rain or 2 or 3 days after a rain.

EFFECT OF DELAY IN REMOVAL OF WEEVILS FROM CAGES

At the suggestion of C. L. Marlatt, at that time chief of the Bureau of Entomology, a special series of tests was started in 1928–29 and continued in the seasons of 1929–30 and 1930–31, to determine the effect on weevil survival of delaying the removal of weevils from cages until the cotton plants in the field were sufficiently large to furnish food for weevils. The removal of weevils from the cages was delayed until May 9 in 1929 and until May 4 in 1930 and in 1931. It will be noted in table 16 that an average survival of 2.62 percent was recorded in the cages where weevils were removed on and after March 1 and that an average survival of 2.06 percent was recorded in the cages where the removal of weevils was delayed until early in May. The average survival in the cages where the removal of weevils was delayed until early in May was 78.6 percent of that recorded in the cages where weevils were removed on and after March 1.

TABLE 16.—*Weevil survival in cages where emergence records were started on Mar. 1 and on May 4 and 9, Tallulah, La., from 1928–29 to 1930–31*

Year	Cages	Nature of shelter	Date emergence records started	Weevils installed	Emergence		Difference in percentages
	Number			*Number*	*Number*	*Percent*	
1928–29	12	Spanish-moss plus cotton stalks.	Mar. 1	5,894	38	0.64	0.44
	12	do	May 9	5,901	12	.20	
	8	Spanish-moss	Mar. 1	3,948	23	.58	.15
	8	do	May 9	3,923	17	.43	
1929–30	10	Spanish-moss plus cotton stalks.	Mar. 1	4,946	0	.00	0
	10	do	May 4	4,922	0	.00	
	8	Spanish-moss	Mar. 1	3,880	0	.00	0
	8	do	May 4	3,857	0	.00	
1930–31	11	Spanish-moss plus cotton stalks.	Mar. 1	5,320	301	5.66	1.42
	11	do	May 4	5,330	226	4.24	
	8	Spanish-moss	Mar. 1	3,887	369	9.49	1.42
	8	do	May 4	3,939	318	8.07	
Total			Mar. 1	27,875	731	2.62	.56±0.17
			May 4 and 9	27,872	573	2.06	

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SUMMARY OF FALL AND SPRING EXAMINATIONS OF SPANISH-MOSS, PERCENTAGES OF SURVIVAL IN HIBERNATION CAGES, EXAMINATIONS OF COTTON PLANTS IN MAY AND JUNE, AND PERCENTAGE OF INCREASED YIELD IN EXPERIMENTAL PLOTS

Table 17 presents records made in the vicinity of Tallulah for the winters from 1915–16 to 1930–31 which show the importance of hibernation-cage records and further show the relation of such records to certain other variables. The most important of these records are presented in figures 8 and 9. Figure 8 shows the minimum temperature for the winter, bollweevil survival (live weevils per ton) in Spanish-moss under natural conditions, and weevil survival in hibernation cages. The two survival curves have practically the same trends. The graph also shows the high degree of correlation existing between weevil survival and minimum temperatures. It is also interesting to note (table 17) that during this period the mini-

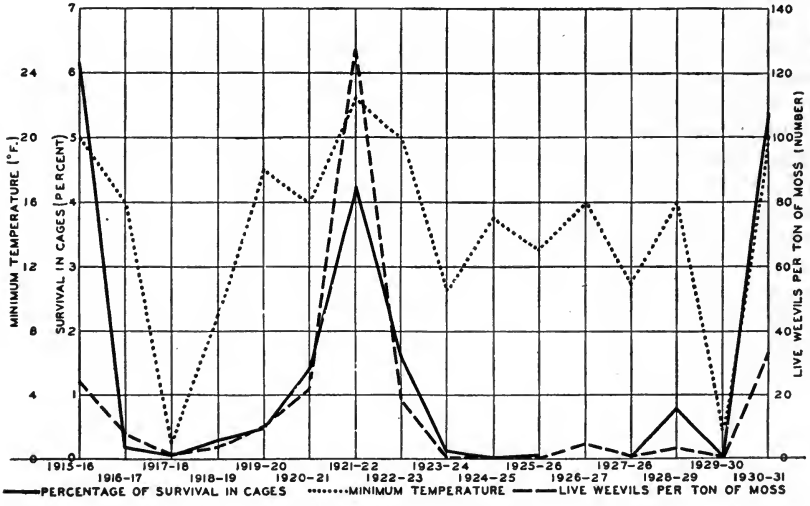

FIGURE 8.—Minimum temperature for the winter, number of live bollweevils per ton of Spanish-moss (spring examination), and bollweevil, survival in hibernation cages, Tallulah, La., 1915–16 to 1930–31.

mum temperature was 20° F. during the winters of 1915–16, 1922–23, and 1930–31; 22.5° during the winter of 1921–22; and lower than 20° during the 11 remaining winters for which survival records of weevils in hibernation cages are available. The average survival for the 4 years that the minimum temperature was 20° or higher was 3.96 percent, as compared with an average survival of 0.29 percent during the remaining 11 years when the minimum temperature fell below 20°.

There is also positive correlation between the minimum temperature of the preceding winter and the percentage of increased yield in experimental plots (table 17) where bollweevils were controlled with calcium arsenate. The coefficient of correlation between these two variables is $+0.44 \pm 0.16$. Kincer [7] showed that there is a definite

[7] KINCER, J. B. WEATHER AND COTTON BOLL WEEVIL. U. S. Monthly Weather Rev. 56: 301–304, illus. 1928.

correlation between the lowest temperature during the preceding winter and the reported bollweevil damage. The correlation coefficients by States are as follows: Texas +0.71, Oklahoma +0.61, Arkansas +0.71, Louisiana +0.63, Mississippi +0.74, Alabama +0.37, and Georgia +0.63.

TABLE 17.—*Summary of fall and spring Spanish-moss examinations, percentage of bollweevil survival in hibernation cages, cotton-plant examinations during May and June, and percentage of increased yield in experimental plots, Tallulah, La., 1915–16 to 1930–31*

Season	Weevils entering hibernation (live weevils per ton of Spanish-moss)	Minimum temperature for winter	Survival in Spanish-moss (live weevils per ton)	Survival in hibernation cages	Cotton-plant examinations in field, May and June (average plants per weevil)	Total precipitation, June to August	Increased yield in calcium arsenate treated plots
	Number	*°F.*	*Number*	*Percent*	*Number*	*Inches*	*Percent*
1915–16	----------	20.0	24.0	6.14	52	10.06	----------
1916–17	----------	16.0	8.0	.17	5,056	10.27	----------
1917–18	----------	1.0	1.7	.05	354	6.26	----------
1918–19	----------	9.0	4.0	.31	245	15.30	----------
1919–20	----------	18.0	9.5	.48	223	12.51	32.8
1920–21	----------	16.0	22.0	1.38	139	12.62	44.6
1921–22	----------	22.5	127.0	4.22	135	21.32	83.9
1922–23	----------	20.0	19.0	1.59	258	9.42	20.7
1923–24	----------	10.5	.5	.11	1,788	2.11	1.1
1924–25	----------	15.0	.6	.01	5,690	9.38	11.7
1925–26	280	13.0	.0	.05	558	10.51	68.3
1926–27	242	16.0	4.0	----------	----------	14.58	33.0
1927–28	21	11.0	1.0	.02	2,016	18.06	41.2
1928–29	240	16.0	3.8	.78	600	6.68	11.7
1929–30	189	1.8	.2	.01	1,511	2.28	9.3
1930–31	49	20.0	33.0	5.34	2,685	13.04	31.8

Figure 9 shows weevil survival in hibernation cages, total precipitation during June, July, and August, and percentage of increased yield in experimental plots where weevils were controlled with calcium arsenate.

The increased yields on dusted plots (as compared with untreated plots) reflect the degree of weevil infestation in the different seasons, since the increase in yield of treated over untreated plots was greater in the seasons of severe infestation. The curves of figure 9 show a marked correlation between increased yield and total precipitation for June, July, and August, except for the season of 1926, in which there was a heavy infestation of the cotton flea hopper, *Psallus seriatus* Reut., and in 1927, the year of the overflow.

This increased-yield curve (which indicates the weevil population) does not follow the survival curve so closely as it does the precipitation curve, showing that the final population depends more on the weather than on the initial infestation.

The correlation coefficient between the percentage of increased yield in the dusted plots and the total precipitation during June, July, and August was $+0.79 \pm 0.07$. Kincer[8] gives the correlation coefficients between rainfall in inches, concurrent year, and reported weevil damage by States as follows: Texas +0.54, Oklahoma +0.70,

[8] KINCER, J. B. See footnote 7.

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Arkansas +0.49, Louisiana +0.78, Mississippi +0.69, Alabama +0.46, and Georgia +0.23. Rainfall for the following periods were used: Texas, June to August, inclusive; Oklahoma, Arkansas, and Louisiana, June and July combined; Alabama and Georgia, July and August combined; Mississippi, June to September, inclusive.

COMPARISON BETWEEN RESULTS AT TALLULAH, LA., AND AT COOPERATING STATIONS

During the last 7 years of this investigation valuable cooperation was extended by a number of workers at State experiment stations and other points of investigation and by the Bureau's laboratory at Florence, S. C.

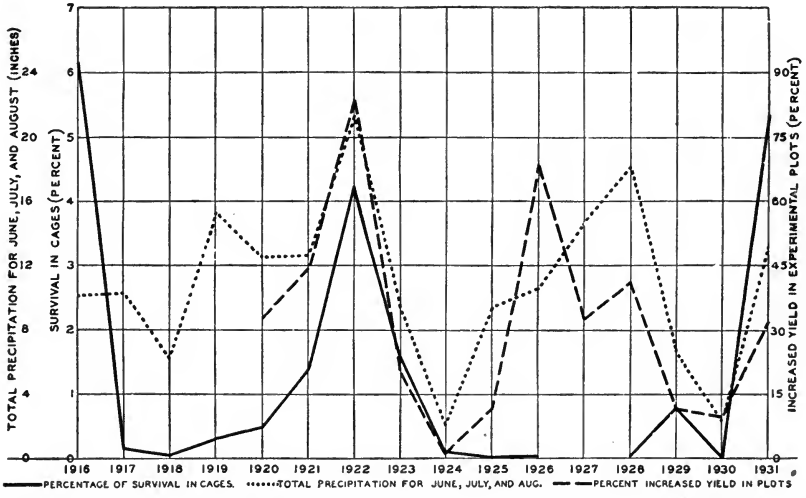

FIGURE 9.—Bollweevil survival in hibernation cages; total precipitation for June, July, and August; and percentage of increase in yield in experimental plots where bollweevils were controlled with calcium arsenate, Tallulah, La., 1916–1931.

In a comparison of the results of the cage tests at Tallulah, with results obtained at the 17 cooperating stations from 1924–25 to 1930–31, as shown in table 18, it will be noted that the average survival in the cages at Tallulah, was consistently lower than the average survival at most of the cooperating stations. This may be in large part due to the fact that at Tallulah, 60.5 percent of the weevils were installed prior to October 16 (table 2), when many of them perished before they entered hibernation, whereas at the cooperating stations only 43.3 percent of the weevils were installed during the same period. At Tallulah, 30.9 percent of the weevils were installed in cages where the hibernation material provided showed average survivals of less than 1 percent over a long period (table 10), while at the cooperating stations, in many cases, more favorable shelters were used.

TABLE 18.—*Percentage of emergence in hibernation cages at cooperating laboratories, 1925–31*

Location of laboratory	Cooperator	1924–25		1925–26		1926–27		1927–28		1928–29		1929–30		1930–31	
		Weevils installed	Weevils emerged	Weevils installed	Weevils emerged	Weevils installed	Weevils emerged	Weevils installed	Weevils emerged	Weevils installed	Weevils emerged	Weevils installed	Weevils emerged	Weevils installed	Weevils emerged
		Number	*Percent*	*Number*	*Percent*	*Number*	*Percent*	*Number*	*Percent*	*Number*	*Percent*	*Number*	*Percent*	*Number*	*Percent*
Aberdeen, N. C	R. W. Leiby	1,072	0.93	2,000	0.85	2,425	3.26	2,500	0.68	2,500	21.36				
Auburn, Ala	J. M. Robinson	1,750	15.71	1,500	.60	3,804	.29	7,008	.07	10,888	.20	2,420	0.00	191	0.00
Baton Rouge, La	W. E. Hinds	7,326	6.61	13,295	6.13	816	.00	3,385	2.13	6,055	.56				
Clemson College, S. C	C. O. Eddy	4,000	3.80	4,000	.25			7,500	1.21	5,600	.54	6,000	.95		
Cleveland, Miss	G. I. Worthington							3,000	.07	2,850	.60	2,800	.00		
College Station, Tex	F. L. Thomas	1,329	6.47	1,430	2.45	3,984	5.27	4,500	.42	5,570	7.74	3,500	.03	5,000	17.00
Experiment, Ga	R. P. Bledsoe	2,781	1.62	8,373	.02	1,097	.00	6,000	.00	750	.00				
Fayetteville, Ark	Dwight Isely					2,000	.30	2,000	.55						
Florence, S. C		19,427	6.50	14,425	.80	15,462	8.49	18,500	1.54	22,000	14.27	22,000	4.82	20,000	5.99
Holly Springs, Miss	T. F. McGehee	1,250	.08	1,350	.00	4,100	.02	5,000	.00	3,500	.29	1,200	.00		
Poplarville, Miss	J. E. Lee			2,000	.10	2,500	.20	2,000	.10	2,000	.00				
Raymond, Miss	O. M. Chance			2,000	.35	2,000	2.05	700	.71	1,000	9.90	2,000	.10		
Rocky Mount, N. C	R. W. Leiby	2,177	.37	3,700	.11	4,300	1.67	4,000	1.40						
State College, Miss	H. H. Kimball			1,130	.09	3,291	.91	4,100	.27	3,972	8.31	5,000	.02		
Stoneville, Miss	D. W. Grimes			8,330	.00										
Tifton, Ga	W. J. Davis			4,000	.98										
Yazoo City, Miss	Chesley Hines							3,000	1.00	3,000	10.43	2,575	.00		
Tallulah, La		33,565	.01	40,376	.05			46,380	.02	33,999	.78	31,786	.01	32,854	5.34

SUMMARY

This bulletin gives the results of a 15-year study of various factors influencing the survival in hibernation of the cotton bollweevil. The study was conducted by using a standard procedure and introducing one variable in each series of tests.

In a study of the effect of time of entering hibernation the highest survival was found among the weevils placed in cages between October 20 and November 18. There was no survival among weevils put into the cages prior to September 7.

The study of the survival in various materials provided in the cages for shelter revealed that the highest percentage of survival was in cornstalks, followed by Spanish-moss, Spanish-moss and cotton stalks, sawmill debris, and oat straw; with a number of other materials and combinations showing a much lower rating.

In a study of the effect of the number of weevils in a cage it was found that the highest percentage of survival in cages 4 by 4 by 4 feet was obtained when from 50 to 250 weevils were used.

Weevils transported from other points were less resistant to winter conditions than weevils collected locally.

In a study of the relation of winter weather conditions to weevil survival it was found that the only significant correlations were between minimum temperatures and survival. Coefficients of correlation between weevil survival and the number of times the temperature fell below 32°, 30°, 24°, 22°, 20°, and 18° F., respectively, were found to be significant, as were also those between weevil survival and the number of times the temperature ranged from 18° to 20° and from 1° to 17° F., and that between weevil survival and the minimum temperature for the winter. The weighted average weevil survival for the 4 years that the minimum temperature for the winter was 20° F. or higher was 3.96 percent, as compared with an average survival of 0.29 percent during the remaining 11 years when the minimum temperature fell below 20° F.

As a result of 15 years' observations at Tallulah, an average winter survival under all cage conditions of 1.22 percent was shown. In a special 3-year study, when the average survival was 2.62 percent in the cages from which the weevils were removed beginning March 1 (the customary procedure), a survival of 2.06 percent was indicated when the recording of the emergence was not begun until the early part of May.

Of the total number of weevils surviving, 15.7 percent emerged in March, 22.9 percent in April, 39.7 percent in May, 21.4 percent in June, and 0.3 percent in July. In other words, emergence was 38.6 percent complete at the end of April, 78.3 percent complete at the end of May, and 99.7 percent complete at the end of June. The emergence period for the different years ranged from 47 to 127 days, with a weighted average of 117 days. The extremely short periods of emergence were during the years of very low survival. Emergence extended into July in only 4 of the 15 years.

The final field population of weevils by the close of the growing season depends more upon the weather than upon the initial infestation.

The survival records obtained at Tallulah, La., were usually much lower than those obtained at 17 cooperating stations.

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EFFECTS OF PARTICLE SIZE ON THE PROPERTIES AND EFFICIENCY OF FERTILIZERS[1]

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INTRODUCTION

The cost of fertilizers to the farmer may be lowered either by reducing the price of goods of the same quality or by improving the quality without proportionately increasing the price. In considering ways of accomplishing the latter, consideration should be given the fact that fertilizer particles of one size may be considerably more efficient than those of other sizes and that if the optimum size were known fertilizers might be prepared accordingly with little or no additional cost.

Insoluble fertilizer materials, such as bone meal, basic slag, and limestone are generally recognized to be of greater value when finely ground, but little is known about optimum sizes for the particles of water-soluble fertilizers or of commercial mixtures.

The problem is very complicated because of the large number of factors involved. For example, since fertilizer materials vary widely in their physical and chemical properties, the size of grains best adapted to prevent caking or to insure good mechanical condition might be inefficient in obtaining high crop yields with a given fertilizer and quite efficient with another fertilizer.

[1] Credit is due G. A. Cumings, Division of Mechanical Equipment, Bureau of Agricultural Engineering, for assistance in applying the fertilizers with the improved distributor belonging to that Bureau; to the officials of the South Carolina Agricultural Experiment Station for provision of land, labor, and other facilities in connection with the field work; to Albert Bowen, Division of Soil Fertility Investigations, Bureau of Plant Industry, for assistance in obtaining the emergence counts and yield data; and to the officials of the South Carolina, Georgia, Tennessee, Ohio, New Jersey, New York, and Minnesota fertilizer control laboratories for furnishing representative samples for the mechanical analyses.

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Factors in the problem of particle size include the properties of various fertilizers, their behavior during storage, their handling and application to the soil, their movements and reactions in the soil solution, and their efficiency in getting good stands and high crop yields. The purpose of this bulletin is to give the results of experiments upon each factor separately and then to show so far as possible their interrelationships and significance to agriculture.

As a result of this work it appears that the size of fertilizer particles is of real importance to agriculture and some suggestions will be offered for getting greater efficiency in the use of fertilizers in this respect. Much more work must be undertaken, however, to determine fully the relationships of particle size to the efficiency of all types of fertilizers under all sorts of conditions.

MATERIAL AND METHODS

Each recognized factor in the problem of particle size in fertilizers was studied separately both from the theoretical and practical viewpoints. The fertilizers studied included a variety of commercial mixed goods obtained from many different sources in a dozen States, typical fertilizer materials and a considerable number of fertilizers prepared specially for the purpose. Among the latter was a series of grained complete mixed fertilizers alike in every respect except that each member of the series was composed of particles of one size.

The size distribution of the grains composing the average mixed fertilizer and representative fertilizer materials was determined by screening. Bulkiness, caking, segregation, and drillability were studied in relation to the size of the particles in fertilizers by making various laboratory tests, some of them with control of the humidity and temperature of the atmosphere. The behavior of various fertilizers was studied carefully while they were poured, bagged, hauled on trucks, and distributed by commercial implements both in the laboratory under controlled conditions and in the field under normal conditions of farm practice. Field tests were made in 1931, 1932, and 1933 with cotton on several extensive soil types. Series of closely screened complete fertilizers varying only in the size of their grains were applied accurately in side placements and mixed with the soil below the seed in these field experiments. Soil samples were gathered at intervals during the growing season, and various chemical determinations were made to find out what effect size of grain had upon leaching and reactions in the soil solution. Rate of emergence of seedlings and yields of cotton were determined also.

PARTICLE SIZE IN COMMERCIAL FERTILIZERS

The grains composing a fertilizer are sometimes all of approximately the same size, as in pellet-form sodium nitrate, but more often vary in size from mere flecks of dust to that of pebbles 5 millimeters or more in diameter. The average diameter in millimeters is the best measurement when the particles are uniform in size or nearly so, but otherwise size is more clearly indicated by the percentages of material separated by a series of screens. A set of screens for this purpose should start with one having 5 or 6 meshes to the inch, with each succeeding screen having twice as many meshes to the inch as the preceding. Relatively small amounts of material larger than the

coarsest or smaller than the finest sieve in the set employed are expressed as on or through the mesh designated. A statement of the proportions of the fertilizer separated by sieves is its mechanical analysis. The mechanical analysis may be reduced to an average diameter if desired by the following method: Multiply the average diameter of the openings of each pair of screens by the percentage of material separated by them, add all the results and divide by 100.

It is necessary to know the actual size distribution of the particles in the more important types of commercial fertilizers to appreciate the practical significance of the results of this study.

Accordingly mechanical analyses were made of a considerable number of samples of commercial fertilizers by weighing the separated portions after 15 minutes treatment in a Rotap screening machine. Some of the samples were obtained directly from manufacturers over a period of several years and others were supplied by officials of the fertilizer control laboratories of New York, New Jersey, South Carolina, Georgia, Tennessee, Ohio, and Minnesota. Table 1 gives the average results. The average for limestone is based on data published by several State fertilizer laboratories.

TABLE 1.—*Average values of mechanical analyses of commercial fertilizers and fertilizer materials*

Fertilizer	Samples	Material separated by screens of mesh sizes indicated						
		On 5	5–10	10–20	20–40	40–80	80–200	Through 200
	Number	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Complete mixtures, 10–19.9 percent plant food	36	1.5	9.7	15.6	25.2	23.3	14.4	10.3
Complete mixtures, 20–29.9 percent plant food	28	.5	7.1	16.0	25.0	25.3	17.4	8.7
Complete mixtures, 30–39.9 percent plant food	6	.4	7.2	15.5	26.6	25.4	19.0	5.9
Complete mixtures, 40–49.9 percent plant food	9	.3	14.6	27.3	22.7	17.4	13.3	4.4
Complete mixtures, 50 or more percent plant food	6	1.3	14.0	13.9	25.4	25.7	15.9	3.8
Superphosphate and potash mixtures	8	.3	5.5	12.9	21.7	36.1	16.9	6.6
Nitrogen and potash mixture	1	.3	.6	11.6	30.8	33.6	20.3	2.8
Sodium nitrate	3	6.7	12.5	26.0	43.9	9.2	1.5	.2
Calcium nitrate	1	.6	10.8	42.3	35.4	9.1	1.7	.1
Leunasalpeter	1	2.4	18.2	8.7	21.4	30.2	19.0	.1
Urea	1				93.4	3.9	2.7	
Ammonium sulphate	3				28.5	59.9	11.3	.3
Ammonium phosphates	4	.4	10.9	24.8	39.9	14.6	8.2	1.2
Raw bone meal	1		3.0	29.5	22.1	20.9	16.4	8.1
Animal tankage	3		12.8	24.2	21.9	20.7	15.9	4.5
Fish scrap	3		4.2	32.6	31.2	16.6	12.3	3.0
Cottonseed meal	1		.4	18.4	25.8	27.1	27.9	.4
Peat	1	.2	1.3	25.6	30.5	19.4	17.5	5.5
Superphosphate, 16–20 percent available phosphoric acid	12	2.8	5.9	7.8	20.8	23.9	19.8	19.0
Double superphosphate, 40–46 percent available phosphoric acid	4	1.1	27.9	20.1	15.6	16.1	11.7	7.5
Muriate of potash	3		4.5	10.7	14.7	32.4	32.3	5.4
Limestone	133		.2	4.0	11.5	13.2	27.1	44.0

The averages for each group of mixed fertilizers in the table are essentially alike but some of the individual analyses in each group differed radically from the average. About half of the mixtures contained no material held on a 5-mesh screen and a few were free of powder that would pass through 80-mesh. The maximum amounts on 5-mesh and through 200-mesh in any of these mixed goods was

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4.8 and 23.5 percent, respectively. Only 1 of the 3 sodium nitrate samples was what is known in the trade as coarse grained and yet the average is much coarser than the mixed fertilizers. The urea and ammonium-sulphate samples consisted largely of 20- to 80-mesh material. On the average the 16- to 20-percent superphosphates were composed of much smaller particles than the double superphosphates. The limestone samples were the most finely ground of all the classes of materials or mixtures.

PHYSICAL AND CHEMICAL PROPERTIES AFFECTED BY PARTICLE SIZE

Physical properties of fertilizers that change considerably with the size of the grains and that have a bearing on the present problem are apparent density, surface tension, capillarity, adhesion, and cohesion.

The apparent density (weight of a unit volume of divided material) varies considerably with the size, shape, degree of packing, and distribution of size of the particles composing it, but the absolute density (weight of a unit volume of solid substance) changes very little over the normal range of atmospheric temperature. The absolute densities or specific gravities of pure substances, such as sodium nitrate and potassium sulphate, are given in appropriate textbooks. The apparent densities of commercial samples of the same materials are quite variable, the values ranging as a rule from 40 to 60 percent of the absolute values. Theoretically, the apparent specific gravities of a material in the form of spheres of uniform size in the loosest and closest packing possible are 52 and 74 percent, respectively, of the absolute density.

A mass consisting of grains of various sizes has a higher apparent density than another of particles of uniform size because small grains fill the spaces between larger ones. Finely ground materials under the same conditions are considerably lighter than coarse ones. This is shown in table 2. A 100-cc lump of solid material after being comminuted to colloidal proportions will often more than fill a liter vessel. This is explained as follows: When 5- to 10-mesh material is reduced to an impalpable dust the area of exposed surface is increased in proportion millions of times. All solid surfaces adsorb films of condensed gases from the atmosphere and thus pulverized material ordinarily contains enormous quantities of adsorbed gases, which increase its bulk.

TABLE 2.—*Variations in densities of masses composed of particles of different shapes with changes in particle size*

Screen mesh size of particles	Monoammonium phosphate crystals	Potassium nitrate spherical pellets	Ground phosphate rock	Screen mesh size of particles	Monoammonium phosphate crystals	Potassium nitrate spherical pellets	Ground phosphate rock
Solid mass	1.80	2.10	3.06	60–80	0.89	1.24	1.28
5–10	.83	1.20	1.25	80–100	.91	1.24	1.28
10–20	.84	1.22	1.24	100–125	.92	1.23	1.28
20–30	.84	1.24	1.24	125–157	.93	1.22	1.28
30–40	.85	1.24	1.25	157–200	.93	1.20	1.28
40–60	.85	1.25	1.27	Through 200	.70	.95	1.12

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Light materials require larger bags to hold the same weight of material. Since large bags cost more than small ones and the storage facilities required for a given tonnage of material vary with the apparent density, it is in the interest of economy to grind materials so as to occupy the least space possible, provided this does not reduce efficiency in some other way. The apparent density approaches its maximum when the pore spaces between the largest particles are filled with smaller ones and the interstices between the latter in turn with still smaller ones and so on until no voids remain.

Molecules in the surface layers of substances behave differently from those in the interior. Molecules inside of a mass are acted on from all sides by the attractive forces of other molecules of the mass but those in the outer layer have one side free from such influences. This leaves residual forces at the surface that give rise to such physical phenomena as surface tension, capillarity, cohesion and adhesion, and the property of adsorption. These forces are all functions of the proportion of surface to mass. The surface area of a particle increases rapidly in proportion to the mass as the size of the particle decreases. When these ratios are plotted against the diameters of the particles the resulting curve is a hyperbola approaching zero with large particles and infinity with those of molecular dimensions. When a mass of particles the size of peas is subdivided finely enough to pass freely through a 300-mesh sieve the free surface of the mass is increased about 1,000 times. By continuing the process of subdivision until the particle diameters are 1 millimicron the free surface of an originally pea-sized grain is increased to about 1 acre. Thus the physical properties of pulverized materials are quite different from those of granular ones. The chemical properties also change when the range of particle size falls between 5 and 200 millimicrons, giving rise to the phenomena of colloid chemistry.

Commercial fertilizers as a rule contain very little material of colloidal proportions but do often contain a fair proportion of minute particles that stick to each other and to almost everything they touch. These small grains also adsorb much larger quantities of gases and moisture from the atmosphere than larger ones do under the same conditions. For these reasons some fertilizers cannot be distributed uniformly by ordinary farm machinery and are unpleasant to handle since they are dusty when dry and sticky when damp. The exact size at which these effects become noticeable varies somewhat with the material and its moisture content.

Experiments were made to determine the size at which physical forces begin to injure drillability or the ability to flow freely as a result of the force exerted by gravity. For this purpose ammonium phosphate was screened into a considerable number of sizes varying from 5- to 8- to 300- to 350-mesh and stored in a constant temperature and humidity room until in equilibrium with the atmospheric conditions. The particles were then tested for steady flow through specially constructed funnels. It was found that when the moisture content was 0.08 percent, masses of particles with diameters of 0.04 mm or less would not flow by gravity but those composed of larger grains did. Similarly the limiting diameters for grains that flowed freely when the substance contained 0.53 and 2 percent of moisture were 0.06 and 0.42 mm, respectively. Thus material drier than that usually found in commerce will not flow by gravity alone when com-

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minuted finely enough to pass through a 300-mesh sieve, although it may flow in the form of 20- to 30-mesh or coarser grains when very damp. Damp materials flow less readily than dry ones of the same particle size because the films of moisture cause the particles to cling together with a tension that increases with the quantity of moisture adsorbed until the capillary spaces between the particles are filled. The smallest sized particles of most fertilizers that would flow by gravity under normal atmospheric conditions were found to be those that pass through a 200-mesh but not through a 250-mesh screen.

Very fine dry powders, such as some ground limestones, that normally show considerable cohesion will, nevertheless, when suddenly jarred flow and surge in waves like a liquid. The jar momentarily separates the particles sufficiently to break the attractive forces between them and as long as they continue to move they flow freely. As soon as they come to rest, however, they cohere again. Many distributors apply such materials with extreme irregularity.

Chemical reactions do not ordinarily occur between molecules that are separated by a space of more than 50 millimicrons (*1*).[2] For this reason coarsely ground materials may be mixed with little or no chemical reaction as long as they are kept dry, while the same materials in solution or pulverized might react instantly or in a fairly short time.

Fertilizer materials when mixed, frequently react to a greater or less extent by double decomposition. The crystal growth of the resulting products often causes the entire mass to harden so that it must be reground before shipment. These reactions between solid materials require considerable time to be completed but the more minutely the materials are subdivided before mixing the shorter this time will be.

BEHAVIOR IN STORAGE AS AFFECTED BY SIZE OF PARTICLES

During storage the moisture content of fertilizers changes with the relative humidity and temperature of the air in contact with them. The amount of moisture held by water-soluble material under a given set of conditions which will not cause actual solution varies little with the size of the grains if they are too large to pass a 200-mesh sieve, but it increases rapidly as the size decreases below this limit.

One of the causes of caking of fertilizers is the alternate absorption of moisture and drying with the diurnal changes of the relative humidity and temperature of the air. When the relative humidity is high a film of moisture is adsorbed upon the surface of the grains and dissolves enough salt from soluble materials to form a saturated solution. When the humidity is lowered water evaporates and crystals are deposited, which cement the grains together. A similar result may also follow variations in the concentration of the solution due to changes in temperature. The extent of this caking varies with the size of the particles.

Caking was studied by screening a variety of fertilizer materials to different sizes and exposing them first to an atmosphere of 90-percent relative humidity and then to one of low humidity. All samples fine enough to pass a 200-mesh sieve were then found to be caked so hard that none could be crushed with the bare hands. The

[2] Italic numbers in parentheses refer to Literature Cited, p. 26.

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5- to 10-mesh particles of some materials were slightly stuck together but crumbled easily when squeezed in the hand, and those of other samples showed no caking whatever. As a result of these experiments and observations in the field it may be said that the smaller the particles of a fertilizer are the more readily they will cement together to form a hard cake and the harder will be the mass formed.

EFFECTS OF SHIPMENT AND DISTRIBUTION UPON FERTILIZERS COMPOSED OF GRAINS OF DIFFERENT SIZES

Some commercial fertilizers though properly mixed at the factory do not remain homogeneous while being shipped or distributed. This was found to be the case by Haigh (*6*) in taking samples for analyses and by Mehring and Cumings (*9*) in testing the distribution of fertilizers by machinery. This tendency for some fertilizer mixtures to separate more or less into zones of like particle size is called segregation. While the relative densities of the different kinds of materials mixed are partly responsible, segregation nevertheless is essentially a problem of particle size.

Smith, Hardy, and Gard (*11*) concluded that different materials when ground to pass through a 200-mesh sieve and well mixed will remain a homogeneous mixture permanently no matter how much it may be jarred or shaken subsequently. Mixtures of coarser sizes than this, however, constitute the overwhelming majority of commercial fertilizers. Some fertilizer mixtures tend to segregate while others do not.

Three kinds of treatment that any fertilizer mixture is likely to encounter may cause more or less segregation. They are pouring, settling, and vibration. Each of these treatments acts differently and will be discussed separately, but all tend to unmix commercial fertilizers.

When a mixture of dissimilar materials is poured in air the largest, heaviest, and most symmetrical particles fall fastest and, after landing in a heap, roll farthest and thus tend to accumulate on the bottom and at the outer edges of the pile. The extent to which segregation takes place increases with the distance through which the material travels. Pouring so that the displaced air rushes up through the descending fertilizer greatly increases the degree of separation in a fall of the same distance. Thus segregation due to this cause while filling sacks or distributors may be materially lessened merely by pouring as short a distance as possible and on one side of the receptacle so that the displaced air may flow out on the other.

Fertilizer immediately after being poured is in a loose condition, but if this loose mass is jarred or shaken, as when a bag is jounced up and down to settle it, or a distributor is hauled over a field, the particles rearrange themselves in tighter packing. The contraction in volume is only about 5 percent and this rearrangement is accomplished in such a way as to have no effect upon the homogeneity of the mixture when the grains are all of about the same size. The average commercial fertilizer, which is composed of many sizes of grains, settles on the other hand from 12 to 25 percent with a mean of about 16 percent and this may be accompanied by considerable segregation.

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When a heterogeneous mixture settles the powdered materials sift down and gradually pack the pore spaces between the granular ones. If each ingredient of the mixture consists of about the same range of sizes this has no effect on composition but if one ingredient is composed of large grains while another is more or less pulverized serious separation may result.

The manner in which this occurs may be clearly demonstrated on a magnified scale by half filling a glass bottle with spheres 10 mm in diameter and then pouring others 4 mm or less in diameter upon the surface of the larger ones. Any other sizes will do as well provided the diameter of the larger ones is at least two and one-half times as great as that of the others. The little balls will run down in zigzag courses through the interstices and fill them up from the bottom.

The same experiment may now be used to show what happens when a mixture is vibrated with a horizontal thrust. To do this the bottle is turned on its side and tapped vigorously on the bottom with the palm of the hand a few times, whereupon the large spheres accumulate on top of the small ones.

The phenomenon of stratification as a result of horizontal vibration occurs at times in distributors with knocking devices and may also take place to some extent in moving freight cars and under other circumstances. This kind of segregation was studied in glass bottles so that the effects could be watched with a wide variety of mixtures composed of two well-mixed substances of known properties. In some cases complete separation into layers was effected by tapping the bottom of the bottle only a few times. Figure 1 shows 8- to 10-mesh superphosphate completely separated in this way from 10- to 16-mesh nitrate of soda. In other tests the materials did not stratify nor even tend to separate. From these tests it may be concluded that when the density of the two materials is approximately the same, the average diameter of one kind must be more than double that of the other before complete separation can be obtained in this way.

Horizontal vibration and settling tend to correct the segregation produced by pouring.

In view of the ease with which some of these mixtures separated, it becomes a matter of interest to know what happens when commercial mixtures are being handled and applied to the soil. This was studied by distributing under controlled conditions a number of typical fertilizers bought on the open market.

Each fertilizer was tested in a star-wheel grain-drill attachment. The fertilizer was first thoroughly remixed in a rotating drum and then placed in the hopper with a scoop to avoid pouring or shaking. After the distributor had been operating for 3 minutes, a sample was collected in a pan placed under the delivery spouts for 1 minute. Every 3 minutes thereafter a sample was gathered for 1 minute. The first, middle, and last samples obtained under normal operating conditions were subjected to chemical and mechanical analyses, the results of which are given in table 3.

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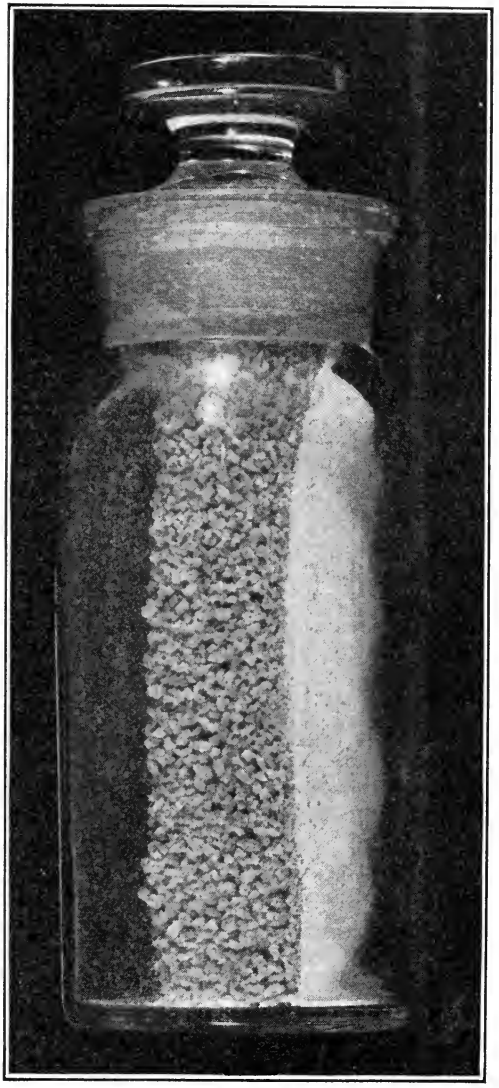

FIGURE 1.—A mixture of 8- to 10-mesh superphosphate and 10- to 16-mesh nitrate of soda completely separated by horizontal vibration. The average diameters of the particles are 2.20 millimeters and 1.61 millimeters, and the apparent densities are 0.90 and 1.30, respectively.

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TABLE 3.—*Chemical and mechanical analyses of the first, middle, and last portions (samples nos. 1, 2, and 3, respectively) of commercial fertilizers delivered by a grain-drill fertilizer attachment and the difference* [1] *between the first and last sample*

Fertilizer no.	Sample no.	Plant food			Material separated by screens of sizes indicated					
		N	P_2O_5	K_2O	On 10-mesh	10- to 20-mesh	20- to 40-mesh	40- to 80-mesh	80- to 200-mesh	Through 200-mesh
		Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
1	1	3.84	10.41	7.07	6.9	12.7	20.9	17.7	16.3	25.5
	2	3.89	10.58	6.88	9.2	15.0	21.3	15.6	14.6	24.4
	3	3.92	10.49	6.11	7.8	12.9	23.3	16.7	18.1	21.2
	Difference	+.08	+.08	−.96	+.9	+.2	+2.4	−1.0	+1.8	−4.3
2	1	3.47	8.99	2.75	5.9	10.4	28.9	24.6	16.2	14.0
	2	3.50	9.05	2.97	6.5	13.6	29.1	22.8	13.6	14.4
	3	3.50	8.15	3.02	7.1	13.9	29.1	22.7	15.4	11.7
	Difference	+.03	−.84	+.27	+1.2	+3.5	+.2	−1.9	−.8	−2.3
3	1	5.63	7.58	3.99	9.7	9.6	22.3	15.5	26.9	15.8
	2	5.63	7.31	3.94	9.2	12.0	24.5	21.2	14.0	19.1
	3	5.13	7.17	4.53	15.1	14.0	27.5	15.7	18.0	9.6
	Difference	−.50	−.41	+.59	+5.4	+4.4	+5.2	+.2	−8.9	−6.2
4	1	3.55	8.34	2.71	9.5	8.8	23.4	22.7	10.1	25.5
	2	3.55	8.50	2.59	9.2	12.3	24.7	22.3	11.9	19.5
	3	3.53	8.13	2.98	9.9	10.9	25.0	24.6	12.6	16.9
	Difference	−.02	−.21	+.27	+.4	+2.1	+1.6	+1.9	+2.5	−8.6
5	1	3.25	8.32	10.75	7.4	12.6	19.6	23.6	16.7	20.0
	2	3.25	8.21	10.54	7.9	14.0	18.0	22.9	16.6	20.6
	3	3.25	8.35	10.72	7.7	11.9	19.9	22.4	16.4	21.8
	Difference	.00	+.03	−.03	+.3	−.7	+.3	−1.2	−.3	+1.8
6	1	3.03	7.67	4.09	5.6	12.3	26.9	26.9	8.8	19.4
	2	3.03	7.81	4.24	7.2	13.2	27.0	25.1	11.3	16.1
	3	3.03	7.85	4.02	9.6	15.8	28.3	22.2	7.1	17.0
	Difference	.00	+.18	−.07	+4.0	+3.5	+1.4	−4.7	−1.7	−2.4
7	1	3.64	16.26	10.24	6.6	10.0	26.4	28.6	9.3	19.0
	2	3.67	16.92	9.79	6.4	14.0	28.9	27.0	12.5	11.3
	3	3.67	18.00	8.70	10.3	16.5	29.2	24.1	10.6	9.2
	Difference	+.03	+1.74	−1.54	+3.7	+6.5	+2.8	−4.5	+1.3	−9.8
8	1	6.84	9.14	18.06	10.8	15.9	21.0	19.4	32.8	.1
	2	7.28	10.06	16.06	14.0	20.4	23.1	16.6	25.9	0.0
	3	8.20	12.63	11.97	26.5	25.2	20.4	11.6	16.3	0.0
	Difference	+1.36	+3.49	−6.09	+15.7	+9.3	−.6	−7.8	−16.5	−.1
9	1	4.61	12.88	4.29	9.1	18.2	26.5	23.5	12.0	10.7
	2	4.71	13.07	4.33	10.9	20.3	25.3	23.2	10.5	9.8
	3	4.72	13.10	4.57	12.6	20.7	23.4	25.3	9.3	8.7
	Difference	+.11	+.22	+.28	+3.5	+2.5	−3.1	+1.8	−2.7	−2.0
10	1	4.05	13.91	3.92	3.7	17.3	33.3	26.1	12.8	6.6
	2	4.09	13.80	4.61	7.8	22.7	31.7	22.4	10.6	4.8
	3	4.10	13.53	4.47	12.7	25.7	27.3	19.9	10.2	4.1
	Difference	+.05	−.38	+.55	+9.0	+8.4	−6.0	−6.2	−2.6	−2.5

[1] Plus (+) indicates that the result for sample 3 is greater and minus (−) that it is less than that for sample 1 of the same fertilizer.

The mechanical analyses of all these fertilizers except no. 5 show an unmistakable tendency for the dust to be delivered first and the gravel sizes last. The chemical composition of a few of these fertilizers remained practically constant throughout the test but in others considerable variation occurred. The analyses of fertilizer no. 8 show that it segregated very badly. It differed from the others in containing no material fine enough to pass through a 200-mesh sieve, and a larger than usual proportion of big granules.

Since the fertilizer that contained no powdered material segregated most, several special mixtures were prepared for study which also were free of powder. Table 4 gives the essential facts regarding the composition of these mixtures and table 5 the results obtained with them in the distributor.

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TABLE 4.—*Specifications of special mixtures prepared to study segregation*

Fertilizer no.	Material	Size of particles, screen mesh	Apparent density	Quantity in 100 pounds of mixture
				Pounds
11	Nitrate of soda	20 to 40	1.31	29
	Superphosphate	5 to 10	1.11	61
	Sulphate of potash	80 to 150	1.30	10
12	Nitrate of soda	20 to 40	1.31	29
	Superphosphate	20 to 40	1.04	61
	Sulphate of potash	20 to 40	.95	10
13	Nitrate of soda	20 to 40	1.31	29
	Superphosphate	80 to 150	1.11	61
	Sulphate of potash	5 to 10	.97	10

TABLE 5.—*Chemical analyses of portions of special mixtures delivered at intervals by a grain-drill fertilizer attachment and from different parts of a sack that had been subjected to vibration*

Description of sample	Plant food content of fertilizer —								
	No. 11			No. 12			No. 13		
	N	P_2O_5	K_2O	N	P_2O_5	K_2O	N	P_2O_5	K_2O
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Entire mixture	4.75	12.87	4.81	4.75	13.06	4.81	4.75	13.52	4.81
First portion delivered	9.21	6.32	6.72	4.95	12.84	4.86	4.73	13.59	4.69
Middle portion delivered	4.65	13.50	3.60	4.88	12.86	4.88	4.68	13.55	4.92
Last portion delivered	1.30	18.69	1.50	4.70	13.09	4.77	5.01	13.37	4.86
Difference [1]	−7.91	+12.37	−5.22	−.25	+.25	−.09	+.28	−.22	+.17
Top of sack	1.94	18.04	1.09	4.80	13.22	4.69	4.88	13.41	4.65
Middle of sack	6.23	10.23	6.56	4.85	13.12	4.79	4.76	13.58	4.63
Bottom of sack	7.05	7.58	10.33	5.00	13.02	4.91	4.65	13.72	4.65
Difference [1]	+5.11	−10.46	+9.24	+.20	−.20	+.22	−.23	+.31	0.00

[1] Plus (+) indicates that the last portion delivered contained more and minus (−) that it contained less than the first portion delivered, by the amount shown.

Some tests were made to determine what might happen to the material in a sack owing to vibration such as might occur in transporting it. For this purpose the special mixtures just mentioned were remixed and packed into burlap sacks, placed on a truck with iron wheels, and hauled about on a cement floor for several minutes. Analyses were then made on samples removed from the top, middle, and bottom of the bag and these results also appear in table 5.

The facts already presented indicate that segregation is greatest when the bulk of the mixture is coarse material and inconsequential when it consists entirely of pulverized material. To make a practical test of these conclusions a bag of commercial 4–8–4 fertilizer was divided into two portions and one part was reground somewhat more finely. The mechanical analyses of the two portions and the results of tests with them in the drill are given in table 6, which proves that while other conditions remain identical finer grinding does greatly decrease the extent of segregation.

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TABLE 6.—*Effect of grinding on segregation of a fertilizer*

	Distribution for screen-mesh sizes indicated						Portion of delivery by distributor	Plant food content		
	5- to 10-mesh	10- to 20-mesh	20- to 40-mesh	40- to 80-mesh	80- to 200-mesh	Through 200-mesh		N	P_2O_5	K_2O
	Per-cent	*Per-cent*	*Per-cent*	*Per-cent*	*Per-cent*	*Per-cent*		*Per-cent*	*Per-cent*	*Per-cent*
Before grinding	52.0	10.8	20.7	8.6	7.2	0.7	First	4.30	7.38	4.22
							Middle	4.06	8.54	4.01
							Last	3.92	8.54	3.79
							Difference[1]	−.38	+1.16	−.43
After grinding	1.7	10.8	24.7	23.4	12.7	26.7	First	3.85	7.83	4.06
							Middle	3.93	7.97	3.99
							Last	3.94	8.08	4.00
							Difference[1]	+.09	+.25	−.06

[1] See footnote Table 5.

In the various experiments just described the nitrogen content of the commercial fertilizers remained much more constant during distribution than did the P_2O_5 and K_2O, but the nitrogen percentages of the special mixtures varied as much as those of the other plant foods. This may have been due in part to the possibility that basing or ammoniation of superphosphate had distributed nitrogen through all the particles in the preparation of the commercial mixtures. It seems, however, to have been due also to the fact that the special mixtures contained only one source of nitrogen, while the commercial mixtures all contained three or more materials supplying it.

PARTICLE SIZE AND DRILLABILITY

The effects of particle size on the drillability of fertilizers have been investigated by Mehring and Cumings (*9*). They found that the rate of delivery and uniformity of distribution along the row by commercial distributors are affected by the dimensions of the particles and under the conditions employed found 20- to 80-mesh the most satisfactory range of size. Drillability was very unsatisfactory when the fertilizer consisted largely of pulverized material. Powders are dusty when dry and pasty when damp. During distribution in windy weather considerable quantities are often carried away to other fields and irritate the eyes and respiratory passages of the operator and team. Such substances will not flow and cannot be distributed satisfactorily. This is illustrated in figure 2, which shows the relative quantities of fairly dry crystalline, granular, and powdered samples of the same fertilizer material delivered by three separated identical units of a grain-drill attachment operating simultaneously.

RELATION OF PARTICLE SIZE TO ACTION IN THE SOIL

Much study has been devoted to finding out the effects of fineness upon the reactions of limestone in the soil. Walker, Brown, and Young (*14*) give a review of a number of these studies. No previous work has been done, so far as is known, to determine the effect of particle size upon the changes in composition, solubility, etc., of commercial fertilizers when they are placed in the soil. From the

results obtained with limestone, however, commercial fertilizers also seemed to be worth investigating in this respect.

Special fertilizers were prepared in several closely screened sizes in such a way as to eliminate the possibility of segregation. This was done by first grinding the materials shown in table 7 to pass through an 80-mesh sieve. The weighed quantities of the proper

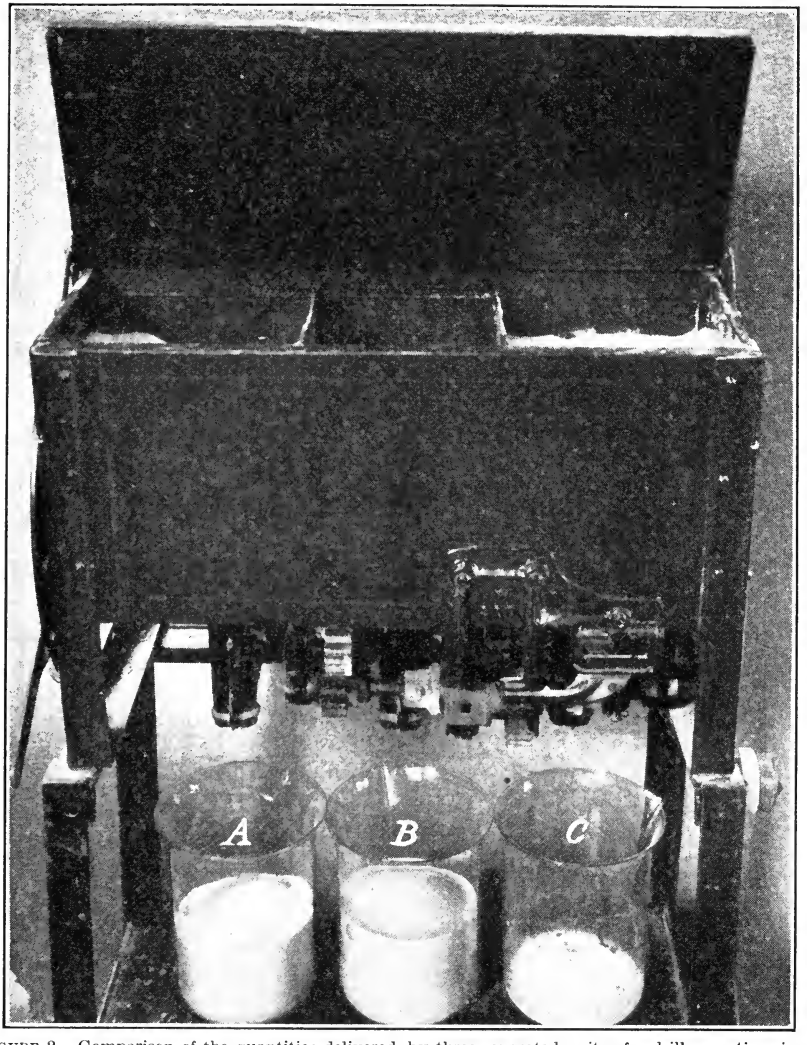

FIGURE 2.—Comparison of the quantities delivered, by three separated units of a drill operating simultaneously, of different samples of the same fertilizer materiel: *A*, Oblong crystals; *B*, granular; *C*, powdered.

ingredients to give the desired grade were then thoroughly dry mixed in a rotating drum and while being mixed were sprayed with water in the form of a mist. The damp material was then dumped into a grainer and agitated at 105° C. until dry. This treatment produced hard pellets most of which contained each of the ingredients in the mixture. The sizes desired were screened out and the oversize material was crushed

and also screened. These grained fertilizers were prepared in 5 different sizes of 4–8–4 grade, 4 of 8–16–8, and 3 of 12–24–12. Dry-mixed fertilizers also were prepared in which only the superphosphate particles varied in size. The other ingredients of the latter mixtures all passed through an 80-mesh sieve. In one of these 4–8–4 mixtures all the phosphoric acid was derived from 5- to 10-mesh superphosphate, in another from 20- to 40-mesh and in the third from finer than 80-mesh particles of the same superphosphate.

TABLE 7.—*Formulas of mixed fertilizers*

Ingredient	Nos. 16 to 23, 4–8–4	Nos. 24 to 30, 8–16–8	Nos. 31 to 36, 12–24–12	Ingredient	Nos. 16 to 23, 4–8–4	Nos. 24 to 30, 8–16–8	Nos. 31 to 36, 12–24–12
	Pounds per ton	*Pounds per ton*	*Pounds per ton*		*Pounds per ton*	*Pounds per ton*	*Pounds per ton*
Sodium nitrate	129	448	----	Double superphosphate	----	712	----
Ammonium sulphate	194	340	----	Potassium sulphate	150	----	----
Ammonium nitrate	----	----	200	Potassium muriate	----	320	480
Ammonium phosphates	----	----	1,196	Filler (sand, etc.)	380	----	124
Cottonseed meal	303	----	----	Dolomite	----	32	----
Dried blood	----	148	----				
Superphosphate	844	----	----	Total	2,000	2,000	2,000

The analyses given in table 8 show that the fertilizers in each grade were essentially alike in chemical composition. The same fertilizers were used in other phases of this study, to be described later, and were therefore given numbers so that the same fertilizer can be identified in various tests.

TABLE 8.—*Analyses of fertilizers used in the field work*

Fertilizer no.	Physical measurements			Chemical analyses									
	Screen mesh sizes [1]	Apparent density	Angle of repose	Total nitrogen	Ammonia nitrogen	Total P_2O_5	Citrate-insoluble P_2O_5	Available P_2O_5	0.002 N H_2SO_4 soluble P_2O_5	Water-soluble P_2O_5	Water-soluble potash	Total water-soluble salts	Moisture
			°	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
16	5 to 10	0.96	39	4.01	2.03	8.44	0.12	8.32	6.88	5.09	4.19	37.5	2.93
17	10 to 20	.93	39	4.23	2.01	8.40	.11	8.29	6.76	5.00	4.25	37.9	2.68
18	20 to 40	.92	39	4.32	2.11	8.48	.10	8.38	6.88	5.09	4.24	38.4	2.64
19	40 to 80	.94	38	4.01	1.91	8.15	.09	8.06	6.99	4.94	3.82	37.6	2.42
20	Through 80	.99	41	3.98	1.91	8.43	.10	8.33	6.78	5.08	3.88	37.3	2.97
21	[2]	1.35	43	4.12	2.05	8.06	.09	7.97	6.75	5.01	3.99	37.9	2.78
22	[3]	1.32	43	3.87	1.95	8.29	.10	8.19	6.80	5.06	3.95	38.1	2.44
23	Through 80 [4]	1.12	44	3.89	1.89	8.44	.11	8.33	6.91	5.10	3.80	38.5	2.40
24	5 to 10	1.02	38	8.24	3.97	16.90	.46	16.44	----	----	7.99	----	1.88
25	20 to 40	1.01	36	8.31	3.99	16.81	.40	16.41	----	----	7.93	----	1.88
26	80 to 150	.97	35	8.11	3.86	16.83	.43	16.40	----	----	7.98	----	2.03
27	2 to 3	.98	38	7.66	[5]	[5]	[5]	17.75	----	----	8.55	----	2.45
28	5 to 10	1.05	39	7.64	[5]	[5]	[5]	17.75	----	----	8.49	----	1.90
29	20 to 40	1.07	37	7.64	[5]	[5]	[5]	17.82	----	----	8.48	----	1.88
30	80 to 150	1.04	34	7.70	[5]	[5]	[5]	17.75	----	----	8.54	----	1.52
31	5 to 10	.87	36	11.87	10.03	25.08	.04	25.04	----	----	13.55	----	5.99
32	20 to 40	.88	35	12.18	10.57	24.56	.04	24.52	----	----	13.56	----	5.66
33	80 to 150	.87	35	11.86	10.10	24.61	.04	24.57	----	----	14.14	----	5.30
34	5 to 10	.93	38	12.02	[5]	[5]	[5]	25.38	----	----	13.73	----	4.67
35	20 to 40	.93	37	12.26	[5]	[5]	[5]	24.68	----	----	13.65	----	4.81
36	80 to 150	.96	35	11.92	[5]	[5]	[5]	24.70	----	----	14.21	----	4.77

[1] All ingredients were grained together in particles of the size indicated except in fertilizers nos. 21, 22, and 23.
[2] 5- to 10-mesh superphosphate, other ingredients through 80-mesh; dry mixed.
[3] 20- to 40-mesh superphosphate, other ingredients through 80-mesh; dry mixed.
[4] All ingredients ground to pass an 80-mesh sieve and dry mixed.
[5] Not determined.

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The grained 4–8–4 fertilizers, of five different particle sizes and the dry-mixed fertilizers each containing superphosphate of a different grain size, were planted with cottonseed in South Carolina in 1931. The fertilizers were applied at the rate of 800 pounds per acre in narrow bands 1½ inches to the sides of the seed on a 2-inch lower level in one test, and were mixed with the soil below the seed in another. The soils used for the experiment were Norfolk very fine sandy loam at Pee Dee Experiment Station, Norfolk coarse sand at Sand Hill Experiment Station, and Cecil sandy clay loam at Clemson College. The planting was done with the distributor described in Department of Agriculture Circular No. 264 (*5*), which gives accurate delivery rates and placements and uniform distribution.

A core of soil 1 inch in diameter with the cottonseed at its center and parallel to the fertilizer band was removed from the row every few days after planting to determine with a soil bridge the amount of soluble salts that had diffused from the fertilizer into this area which will be called the seed zone. This was done by removing a small part of the row and exposing a cross section at right angles to it. The cross section was then whittled down with a spatula until a seed was found, whereupon a 1-inch cork borer was shoved into the soil parallel to the row with the seed in its center. Further details of the method of obtaining the samples and of making the determinations together with rainfall and soil-moisture data, applying equally well to these experiments, are given in Circular 264 (*5*).

Table 9 gives the results of the analyses, which show that more soluble salt was carried into the seed zone from the fertilizer mixed with the soil below the seed than from that at the sides. Any differences in the amounts of salts so transported due to the size of the fertilizer grains are obscured by the errors involved in making the test.

TABLE 9.—*Concentration of soluble salts in the seed zone as a result of 800-pound-per-acre applications of 4–8–4 fertilizers composed of differently sized grains and at several placements*

Fertilizer no.	Size, screen mesh	Fertilizer placement	Concentration of soluble salts in parts per million of soil									
			Norfolk very fine sandy loam [1]			Norfolk coarse sand [2]				Cecil sandy clay loam [3]		
			Apr. 18	Apr. 21	May 1	Apr. 25	Apr. 28	May 7	May 13	May 9	May 16	May 25
(4)			113	120	81	41	25	45	27	52	37	63
16	5 to 10	Bands 1½ inches each side 2 inches below level of seed	117	116	252	42	34	96	36			
17	10 to 20		109	119	305	78	36	77	93			
18	20 to 40		115	117	297	63	38	178	84			
19	40 to 80		108	120	410	73	34	98	42			
20	Through 80		109	118	344	50	37	96	45			
16	5 to 10	Mixed with soil below seed	130	375	895	198	34	222	109	150	432	1,761
17	10 to 20		126	832	1,152	269	478	879	632	146	249	318
18	20 to 40		120	755	763	60	850	458	312	725	350	1,241
19	40 to 80		117	735	974	97	292	539	153	234	1,177	697
20	Through 80		143	156	827	1,622	145	960	2,189	285	1,027	1,243
21 [5]	5 to 10	Bands 1½ inches each side 2 inches below level of seed	118	120	403	62	37	67	143	55	80	102
22 [5]	20 to 40		129	123	434	48	60	257	70	39	50	95
23 [5]	Through 80		123	121	328	41	35	74	52	36	44	83

[1] Fertilizer applied Apr. 17.
[2] Fertilizer applied Apr. 24.
[3] Fertilizer applied May 1.
[4] No fertilizer.
[5] Superphosphate varied in size; all other ingredients through 80-mesh.

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Samples of soil from the fertilizer zone also were removed 100 days after application in order to determine changes that may have occurred in composition and availability of plant food. Duplicate composite samples, each composed of four 1-inch cores of soil with part of the fertilizer band at the center, were analyzed chemically as follows: A weighed quantity of the well-mixed sample was placed in a collodion sack and dialysed. Water-soluble P_2O_5 was determined by the improved Deniges method (*13*) and K_2O by the Association of Official Agricultural Chemists' method on aliquots of this extract. Dilute sulphuric acid-soluble P_2O_5 was determined on another portion of soil by Truog's method (*12*). Total P_2O_5 was determined volumetrically on a solution made by evaporating to dryness a suspension of the soil in magnesium nitrate solution, igniting and extracting with hydrochloric acid. Base exchange K_2O was extracted with N/20 HCl and then determined by the official method. Total soluble salts were estimated with a soil bridge. Total nitrogen and moisture were also determined by official methods. Table 10 gives the average results. The determinations show the sum of the plant food already in the soil plus that from the added fertilizer.

TABLE 10.—*Analyses of soil to which 4–8–4 fertilizers of varying particle size had been applied 100 days previously*

Soil	Fertilizer		Total P_2O_5	0.002 N H_2SO_4 soluble P_2O_5	Water-soluble P_2O_5	Total N	Base exchange K_2O	Water-soluble K_2O	Total soluble salts	Moisture
	No.	Particle size, screen mesh	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
Norfolk very fine sandy loam.	No fertilizer		0.056	0.009	0.002	0.11	0.002	0.001	0.007	7.28
	16	5 to 10	.222	.094	.015	.16	.041	.019	.274	
	17	10 to 20	.128	.052	.009	.14	.016	.009	.199	
	18	20 to 40	.128	.046	.010	.14	.019	.009	.203	
	19	40 to 80	.133	.056	.012	.14	.018	.014	.173	
	20	Through 80	.098	.034	.005	.12	.016	.003	.034	
	No fertilizer		.040	.010	.002	.04	.009	.001	.006	5.00
	21 [1]	5 to 10	.278	.129	.038	.06	.021	.013	.226	
	22 [1]	20 to 40	.072	.021	.006	.03	.008	.001	.035	
	23 [1]	Through 80	.084	.032	.007	.04	.009	.006	.050	
Norfolk coarse sand	No fertilizer		.041	.010	.000	.02	.002	.001	.005	3.68
	16	5 to 10	.113	.048	.006	.05	.003	.002	.231	
	17	10 to 20	.080	.039	.003	.05	.004	.003	.178	
	18	20 to 40	.102	.041	.006	.04	.003	.001	.151	
	19	40 to 80	.104	.062	.008	.04	.011	.007	.152	
	20	Through 80	.076	.034	.002	.03	.006	.003	.083	
Cecil sandy clay loam.	No fertilizer		.103	.008	.000	.12	.005	.001	.014	6.32
	16	5 to 10	.308	.084	.008	.15	.018	.016	.315	
	17	10 to 20	.290	.072	.006	.16	.028	.021	.262	
	18	20 to 40	.344	.085	.008	.16	.037	.014	.237	
	19	40 to 80	.309	.075	.006	.16	.032	.011	.323	
	20	Through 80	.254	.083	.004	.14	.042	.010	.260	

[1] Superphosphate varied in size. All other ingredients through 80-mesh.

Comparison of the determinations directly is not satisfactory since the fertilizer was mixed with different amounts of soil in each sample. Differences in behavior may be seen readily, however, first by reducing to ratios the amounts by which one kind of determination exceeds that on the soil alone as compared with a similar excess of another kind of determination on the same sample and then by comparing these ratios with corresponding ones for samples of other-sized fertilizers.

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Actual analyses made on the soil 1 day after application and 100 days later show that most of the P_2O_5 added to the loam soils was still there at the later date, although in the coarse sand the quantity was reduced to less than half with the largest grains and the amount removed increased as the diameters decreased. Since the value of total P_2O_5 changed very little in some instances and much less than did any of the other determinations in every case, the value for total P_2O_5 was used as the numerator in all of the fractions expressing these ratios.

An increase in value of the ratios for the fertilizer that had lain in the soil over those for the corresponding original fertilizer indicates a loss of the component represented by the denominator either by conversion to a form not soluble in the solvent employed in the determination or by removal from the soil included in the sample either by the cotton plants, by percolating rain water, or by other means.

Table 11 shows that P_2O_5 was reverted to less soluble forms in all cases but in the 5- to 10-mesh superphosphate dry mixture more P_2O_5 remained in a water-soluble condition than in any other fertilizer. When the ingredients were all grained together, reversion appears to have been greatest with the smallest grains, and the net effect was even greater than indicated because a little less total P_2O_5 remained in the smallest particles.

TABLE 11.—*Ratios between determinations of plant food in fertilizers (nos. 16–23, inclusive) of varying particle size, and between the same determinations 100 days after application in soils*

Kind of ratio	Size of particles, screen mesh	Fertilizer alone	Norfolk very fine sandy loam	Norfolk coarse sand	Cecil sandy clay loam
Total P_2O_5 / Dilute H_2SO_4 soluble P_2O_5	5 to 10	1.2	2.0	2.0	2.7
	10 to 20	1.2	1.7	2.1	2.9
	20 to 40	1.2	2.0	2.2	3.1
	40 to 80	1.2	1.6	1.9	2.9
	Through 80	1.2	1.7	2.2	2.4
	Superphosphate 5 to 10	1.2	2.0	(1)	(1)
	Superphosphate 20 to 40	1.2	2.3	(1)	(1)
	Superphosphate through 80	1.2	2.0	(1)	(1)
Total P_2O_5 / H_2O soluble P_2O_5	5 to 10	1.7	13.7	11.7	25.5
	10 to 20	1.7	12.7	9.5	30.8
	20 to 40	1.7	10.8	9.4	29.8
	40 to 80	1.7	8.5	8.3	30.9
	Through 80	1.6	18.3	17.0	41.8
	Superphosphate 5 to 10	1.7	6.7	8.9	20.3
	Superphosphate 20 to 40	1.7	8.0	13.5	28.5
	Superphosphate through 80	1.7	8.8	16.0	62.2
Total P_2O_5 / N	5 to 10	2.1	3.4	3.5	20.6
	10 to 20	2.0	8.1	2.0	4.2
	20 to 40	2.0	5.3	2.4	9.3
	40 to 80	2.0	2.9	4.5	20.2
	Through 80	2.1	9.2	6.5	11.9
	Superphosphate 5 to 10	2.0	11.9	(1)	(1)
	Superphosphate 20 to 40	2.1	10.7	(1)	(1)
	Superphosphate through 80	2.2	12.3	(1)	(1)
Total P_2O_5 / H_2O soluble K_2O	5 to 10	2.0	8.8	14.5	12.4
	10 to 20	2.0	7.8	12.0	10.0
	20 to 40	2.0	7.3	19.7	18.8
	40 to 80	2.1	7.8	19.2	22.8
	Through 80	2.2	17.5	34.5	17.9
	Superphosphate 5 to 10	2.6	29.8	(1)	(1)
	Superphosphate 20 to 40	2.1	32.0	(1)	(1)
	Superphosphate through 80	2.2	11.0	(1)	(1)
Total P_2O_5 / Base exchange K_2O	5 to 10	2.0	4.7	26.0	16.1
	10 to 20	2.0	4.5	7.5	10.8
	20 to 40	2.0	8.4	30.1	10.9
	40 to 80	2.1	7.0	5.8	10.7
	Through 80	2.2	5.6	10.0	5.2

[1] Tests were not conducted.

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Leaching of nitrogen appears to have been greater from the smallest sized particles and this was actually somewhat greater than indicated by the ratios for the reason again that the total P_2O_5 was a little less.

Water-soluble potash disappeared from the soil in all cases but to a greater extent when the smallest sized particles were used. In the Norfolk soils much of it was lost but in the clay loam a considerable percentage was still present as base-exchange potash.

Some similar experiments were made in 1933 on the Norfolk coarse sand with 8–16–8 and 12–24–12 fertilizers, but only a few determinations could be made on each sample of soil. The results of the analyses are given in table 12, which shows that removal of water-soluble salts proceeded much more rapidly from the smallest particles of both fertilizers and varied inversely with the size of the particles. The 12–24–12 fertilizers were composed of more readily soluble materials and the amount of loss from them was also greater. Nitrogen constituted about 20 percent of the soluble salts of the original fertilizers but after 100 days in the soil it was about 1 percent or less. Thus nitrogen was removed either by the plants, by leaching rain water, or by micro-organisms much more rapidly than were soluble salts as a whole and it disappeared most rapidly from the smallest particles. The rainfall during the period of the 1933 experiments is given in table 13.

TABLE 12.—*Water soluble salts and nitrogen remaining in the fertilizer placement zone of the Norfolk coarse sand 100 days after application*

Screen mesh size	8–16–8 fertilizers nos. 27 to 30		12–24–12 fertilizers nos. 34 to 36	
	Water-soluble salts	Nitrogen	Water-soluble salts	Nitrogen
	P.p.m.	*P.p.m.*	*P.p.m.*	*P.p.m.*
2 to 3	518±25	2.9±0.8		
5 to 10	443±69	1.1± .2	86±8	0.7±0.005
20 to 40	209±81	1.0± .1	63±2	.5± .04
80 to 150	122±80	.9± .02	39±13	.7± .03
No fertilizer	<15	<0.3	<15	<0.3

TABLE 13.—*Daily rainfall on the Norfolk coarse sand from Apr. 1 to Aug. 1, 1933*

Date	Rainfall	Date	Rainfall	Date	Rainfall	Date	Rainfall
	Inches		*Inches*		*Inches*		*Inches*
Apr. 7	0.25	May 17	0.06	July 1	0.06	July 21	1.19
Apr. 10	.27	May 28	.31	July 2	.08	July 27	.49
Apr. 15	.11	May 31	1.64	July 4	.19	July 28	.02
Apr. 16	.09	June 7	.41	July 11	.41	July 30	.15
Apr. 19	.23	June 13	.25	July 12	.67		
Apr. 25	.05	June 25	1.71	July 13	.02	Total	11.89
May 3	1.44	June 28	.06	July 18	.73		
May 8	.25	June 30	.06	July 20	.69	Normal	15.50

AGRONOMIC RESULTS

Some previous work that has a bearing on the effects of particle size of fertilizers in relation to crop yields should be mentioned. Lyon (*8*) found that of the sizes tested 50- to 80-mesh limestone particles were most effective. Very large grains required years to produce expected effects, while pulverized material gave quick results.

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Conner and Adams (*4*) experimented with rock phosphate that varied from fairly coarse material to that of colloidal dimensions and found it to be more efficient as the size was reduced all the way down the scale. Recently Conner (*3*) compared powdered and granulated soluble phosphates on corn. The powdered superphosphate was found to be much more efficient than the granular product when applied in a band and less so when mixed with the soil. On the other hand Chucka and Lovejoy (*2*) found that granular cyanamid was superior to the pulverized form for potatoes. Leaching of soluble salts and fixation of phosphates are so excessive in certain Hawaiian sugarcane soils that Hance (*7 pp. 59–60*) pressed commercial fertilizer into briquettes and covered them with paraffin in an attempt to combat too rapid loss of available plant food. One of these briquettes applied to each plant gave much better results than the untreated fertilizer distributed in the usual way.

As a part of the present study, tests were made with cotton in South Carolina during 1931, 1932, and 1933. All the plantings previously described were used for this phase of the study as well, and some additional plantings were made on the same soils for this part of the study only.

The preparation and composition of the fertilizers have been described in the previous section. The seed were acid-delinted and of high germinating power. They were planted simultaneously with the fertilizers in several placement relationships by the improved machine already mentioned at a rate of 1 bushel per acre. The 4–8–4, 8–16–8, and 12–24–12 fertilizers were applied at rates of 800, 400, and 267 pounds per acre, respectively. The plots consisted of 50-foot rows spaced 3.5 feet apart and were guarded at ends and sides by additional planting. Every test was replicated from 10 to 16 times, usually 12 times, in different parts of the field in a random arrangement. Checks for each test were treated in exactly the same way except that no fertilizer was applied to them.

The criteria used for determining relative efficiencies are stand counts and yields of seed cotton.

The number of living plants aboveground on each plot was counted every few days after planting and table 14 gives the average results for each treatment, with their probable errors. The soil moisture at planting time and some pertinent rainfall data which may be of interest in interpreting these results are given in table 15. Seedlings with fertilizer of the largest sized particles located at the sides came up just a little more rapidly than the unfertilized ones but when powdered fertilizer was employed in the same placement emergence of seedlings was delayed, especially when the soil moisture was high. All the fertilizers seriously delayed the appearance of plants aboveground when they were mixed with the soil below the seed and those of intermediate size appear to have done so to a greater extent than those of either the largest or smallest size.

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TABLE 14.—*Number of cotton plants appearing aboveground per 50-foot row when fertilized with complete mixtures of various particle sizes*

Fertilizer			Norfolk very fine sandy loam, planted Apr. 17, 1931			Norfolk coarse sand, planted Apr. 24, 1931			Cecil sandy clay loam, planted May 1, 1931		
Number [1]	Screen mesh size	Placement	Apr. 29	May 6	May 19 [2]	May 4	May 11	May 22 [2]	May 10	May 13	May 26 [2]
No fertilizer		Bands 1.5 inches to each side—2 inches below level of seed.	203±11	221±12	169±11	354± 8	345±11	276±10			
16	5 to 10		224± 7	216±10	167± 8	358± 8	335±10	281±11			
17	10 to 20		196± 8	186±10	144± 8	354±10	326± 9	259±12			
18	20 to 40		161± 8	155±12	118± 9	324± 7	318± 8	259±10			
19	40 to 80		158±10	150±12	120±10	316± 7	302± 7	242± 8			
20	Through 80		166±10	162±12	129±11	320± 6	306± 3	263± 5			
No fertilizer		Mixed with soil below seed	155±16	192±20	140±15	268± 8	241± 7	217± 6	123± 6	395±11	430± 7
16	5 to 10		29± 7	54±14	31± 8	217±15	279±10	216±10	74± 6	282± 9	304±10
17	10 to 20		36±12	52±16	33±11	107±15	178±11	128± 7	67± 8	312±13	326±11
18	20 to 40		8± 2	21± 5	13± 3	174±16	225±15	185±14	64± 6	335±12	345±11
19	Through 80		15± 3	35±10	25± 7	180±13	245±12	211±14	69± 8	344±11	368± 7
20			31± 8	60±16	42± 8	118±15	190±16	144±13	77± 7	362± 7	399± 8
No fertilizer		Bands 1.5 inches to each side—2 inches below level of seed.	203±11	221±12	169±11	354± 8	345±11	276±10	148±10	429± 6	443± 5
21	Superphosphate 5–10.		140±18	175±22	141±19	316± 7	318±11	255±16	145± 1	417± 3	433± 5
22	Superphosphate 20 to 40.		132±14	173±21	137±18	321±11	313± 9	258±12	133± 6	408± 5	430± 5
23	Superphosphate through 80.		131±17	169±21	134±19	352±18	344±13	292±14	135± 5	410± 4	413± 6
			Planted Apr. 14, 1932			Planted Apr. 21, 1932					
			Apr. 25	May 2	May 12 [2]	Apr. 30	May 6	May 16 [2]			
No fertilizer		Bands 3 inches to each side—2 inches below level of seed.	213±9	306±8	348±4	173±17	441±10	586±5			
24	5 to 10		230±4	355±3	360±3	192±25	443±10	554±6			
25	20 to 40		223±9	341±7	363±3	214±21	452±12	581±6			
26	80 to 150		223±5	323±5	346±4	210±22	473±15	599±6			
31	5 to 10		203±5	310±4	348±3	155±17	412± 8	559±5			
32	20 to 40		202±8	307±6	346±4	146±17	443± 6	574±6			
33	80 to 150		195±7	286±6	327±4	168±15	414±10	548±6			
			Planted Apr. 18, 1933			Planted Apr. 21, 1933					
			May 2	May 9	May 16 [2]	May 3	May 12	May 20 [2]			
No fertilizer			372±12	503±5	511±4	248±10	369±6	321±9			
27	2 to 3		381± 7	494±5	489±4	241± 8	387±4	361±5			
28	5 to 10		385± 4	505±2	513±4	285± 8	384±5	365±4			
29	20 to 40		365± 7	506±5	513±5	280± 8	404±4	382±5			
30	80 to 150		379± 6	507±5	516±4	282± 6	406±5	388±4			
34	5 to 10		377± 5	500±6	510±5	299± 8	422±4	395±4			
35	20 to 40		376± 5	510±3	514±4	268± 7	396±3	371±4			
36	80 to 150		365± 7	483±4	492±4	254±10	386±6	365±7			

[1] For particulars about the fertilizers see tables 7 and 8.

[2] The final counts include only living plants.

TABLE 15.—*Soil moisture at planting and rainfall during first 6 weeks after planting and during period from April 1 to October 1*

Year	Norfolk very fine sandy loam			Norfolk coarse sand			Cecil sandy clay loam		
	Soil moisture	Rainfall		Soil moisture	Rainfall		Soil moisture	Rainfall	
		First 6 weeks	Apr. 1–Oct. 1		First 6 weeks	Apr. 1–Oct. 1		First 6 weeks	Apr. 1–Oct. 1
	Percent	*Inches*	*Inches*	*Percent*	*Inches*	*Inches*	*Percent*	*Inches*	*Inches*
1931	9.03	7.38	23.90	5.36	4.69	20.37	12.41	10.47	21.98
1932	9.78	4.23	25.26	3.60	2.48	23.10	----	----	----
1933	7.94	5.80	20.13	7.92	3.75	17.41	----	----	----

After the third count the plants were thinned to a stand of two to the foot wherever possible. The final stand at picking time was practically perfect wherever the fertilizer was applied at the sides but was broken wherever it was mixed with the soil below the seed.

Table 16 presents the total yields of seed cotton. In most cases these are the sum of three separate pickings.

TABLE 16.—*Yields per acre of cotton from fertilizers with grains of various sizes*

Fertilizer no.[1]	Size of particles, screen mesh	Norfolk very fine sandy loam		Norfolk coarse sand		Cecil sandy clay loam	
		Narrow bands to each side of seed, 2 inches lower level	Mixed with soil below seed	Narrow bands to each side of seed, 2 inches lower level	Mixed with soil below seed	Narrow bands to each side of seed, 2 inches lower level	Mixed with soil below seed
		Pounds	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*
1931							
No fertilizer	----	818±67	361±44	244±17	352±15	658±25	633±32
16	5 to 10	1,492±64	603±65	640±32	544±18	----	1,011±28
17	10 to 20	1,355±48	365±73	552±24	503±17	----	982±22
18	20 to 40	1,358±56	265±48	578±26	498±17	----	969±10
19	40 to 80	1,285±42	414±81	517±21	570±30	----	956±16
20	Through 80	1,540±83	554±75	534±20	524±13	----	957±17
21	Superphosphate 5 to 10	1,007±101	----	512±27	----	982±25	----
22	Superphosphate 20 to 40	1,077±87	----	564±27	----	956±24	----
23	Superphosphate through 80.	1,224±92	----	605±22	----	991±26	----
1932							
No fertilizer	----	1,791±47	----	159±15	----	----	----
24	5 to 10	1,895±47	----	674±34	----	----	----
25	20 to 40	1,811±46	----	721±33	----	----	----
26	80 to 150	1,932±47	----	734±24	----	----	----
31	5 to 10	1,829±29	----	537±37	----	----	----
32	20 to 40	1,966±20	----	590±41	----	----	----
33	80 to 150	1,810±38	----	600±38	----	----	----
1933							
No fertilizer	----	1,792±40	----	123±19	----	----	----
27	2 to 3	2,139±30	----	668±23	----	----	----
28	5 to 10	2,138±32	----	637±26	----	----	----
29	20 to 40	2,053±35	----	740±21	----	----	----
30	80 to 150	2,156±40	----	765±24	----	----	----
34	5 to 10	2,110±30	----	365±31	----	----	----
35	20 to 40	2,084±27	----	444±32	----	----	----
36	80 to 150	2,183±45	----	540±32	----	----	----

[1] For description and analyses of fertilizers see tables 7 and 8.

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In 8 of the 13 trials using grained fertilizers the smaller than 80-mesh particles produced the highest yields and 7 of these 8 occurred in 1932 and 1933. The largest sized grains were best in this respect in 3 of the 5 remaining tests, all of which happened to be in 1931. In a majority of the tests the intermediate-sized particles gave poorest yields.

The differences in yield in nearly all of these 13 tests is from 3 to 6 times as large as the probable error, and similar tests gave consistent results as a rule. It may be concluded, therefore, that the differences in yield in general are due to differences in the size of the fertilizer particles, but the significance of individual determinations should be interpreted with caution for it is possible by chance for one average to be 3 times the probable error too high and another in the same test three times the probable error too low, although extreme cases of this kind are not likely to happen often.

Two or three individual determinations are not consistent with the others. If these are assumed to be erratic and due to uncontrolled variance, it is clear that two factors are operating, one to make the little particles most efficient in increasing yields and the other favoring the big grains. Both appear to operate simultaneously, but the latter appears to have been more important in 1931 and the other far more influential in 1932 and 1933. This fact suggests the possibility of weather conditions being involved.

Table 15 gives the rainfall during the first 6 weeks after each planting and for the entire growing seasons. There is a very close correlation between the amount of rainfall during the first 6 weeks and the different results in different seasons, although the total rainfall is essentially the same in each season. During 1931 the rainfall was above normal during the first 6 weeks after planting at each of the three points in this experiment. In 1 week, immediately after planting, 7.7 inches of rain fell on the Cecil soil. This unusually heavy rainfall on the Cecil soil may account for the largest particles producing the largest yields on this soil. In both 1932 and 1933 the rainfall during the month immediately after planting on the Norfolk coarse sand was only about half of the normal amount. In these cases the largest particles of both fertilizers were poorest and the smallest best in increasing yields.

In the case of the dry-mixed fertilizers the one containing the smallest sized superphosphate was most efficient in each of the three trials and in both of the Norfolk soils decidedly more so.

When only the size of the superphosphate particles was varied the tendency for the smallest to be most effective in increasing yields was much more marked than when the size of all the ingredients was varied in the grained fertilizers. This fact seems to indicate that some other ingredient of the mixture was more efficient in larger particles. The soil analyses show that nitrogen disappeared very rapidly under the conditions of these experiments from particles of all sizes but most quickly from the little ones. On the other hand the phosphoric acid was undoubtedly more readily available to the plants from the smallest particles but the soil analyses show that very little loss of P_2O_5 from leaching could have occurred in any case. These differences between phosphates and nitrogenous salts may be the explanation for maxima at both ends of the yield curves in some cases. No experiments were

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conducted in which the sizes of the nitrate or the potash particles were varied while those of the other materials were held constant, but such tests would be of value.

GENERAL DISCUSSION

The problem of what size of particle is preferable in the manufacture of fertilizers is very complicated. Even if the best size for every phase of fertilizer efficiency were definitely known the problem would still be involved because there are so many phases. The best size for one purpose may be bad for another and it is difficult to evaluate the relative importance of each.

Without doubt the most important consideration is the ability to increase crop yields under average conditions. Under the conditions of these experiments the smallest sized fertilizers used increased yields most, but there were indications that a combination of small superphosphate and large nitrogenous particles would be better in years of heavy rainfall. These observations are entirely consistent with the conclusions of Conner (*3*) and of Chucka and Lovejoy (*2*) but much more work with various crop, soil, placement, and climatic conditions needs to be done before this phase of the problem can be considered as solved.

In the present experiments the fertilizer was applied uniformly, but many of the machines used by farmers apply fertilizers irregularly. Mehring and Cumings (*10*) have shown that fertilizers are at least half again as efficient when uniformly applied as when distributed in the manner typical of many commercial distributors. Most farm implements cannot apply pulverized fertilizers uniformly but, as a rule, do a fairly good job with granular materials.

Reasons for avoiding powders are: That they are more difficult to distribute uniformly; they absorb more moisture from the air, and do it more rapidly; they show a much greater tendency to cake; they are dusty in dry weather and sticky in damp weather; they are wasteful and annoying to distribute in windy weather; they are bulky and require larger sacks and more storage room; they sometimes sift through burlap sacks, and in general are more disagreeable to handle than granular materials.

On the other hand powdered materials do not segregate when mixed, while mixtures consisting mostly of large particles may segregate badly. Aside from the misunderstandings that arise when the control chemist analyzes such mixtures, segregation is very undesirable from the standpoint of the consumer because if a certain ratio of the plant-food elements is best for a crop under any given set of conditions and a segregating fertilizer is used of even the best composition to meet these conditions, nevertheless very few of the plants in the field will get the plant food needed for optimum results. Segregation can be prevented by grinding the mixture finely enough to pass through a 200-mesh sieve. Grinding fertilizers to this fineness, however, is difficult, and produces an undesirable product in other ways. Fortunately other methods are available for preventing or greatly minimizing segregation. For example, it has been found that when all the ingredients for a mixture are ground together rather than separately the lightest material is comminuted most because density and hardness usually vary together. This treatment greatly reduces the tendency to

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separate. When all the well-mixed components are cemented together, as by basing or graining operations, separation through handling of the mixture is impossible.

At present prices the average cost of the plant food in the grained fertilizers used in these experiments would be $9.86 per acre. The average difference in yield of cotton resulting from the use of the 80- to 150-mesh fertilizers over that obtained with 20- to 40-mesh in 13 tests was 59 pounds per acre, by itself worth at present prices about $7, or nearly as much as the total cost of the fertilizer. The dry-mixed fertilizers with 5- to 10-, 20- to 40- and through 80-mesh superphosphate produced 269 ± 16,[3] 301 ± 5, and 375 ± 17 pounds more cotton per acre, respectively, than the unfertilized checks. The difference of 106 pounds between the yields with the largest and smallest superphosphate particles is highly significant and at 12 cents per pound is alone worth $12.72, or considerably more than the entire cost of the fertilizer.

It will be recalled that the average 16- to 20-percent superphosphate examined in this study contained only 38.8 percent of material finer than 80-mesh and that the average double superphosphate contained less than 20 percent.

It does not seem desirable at present to grind and screen fertilizers to definite sizes as special operations, because this would add unnecessarily to the cost of manufacture. In the process of making commercial fertilizers, however, certain grinding and screening operations are necessary and in many cases it will be a simple matter to substitute another mesh screen for one already in use or to adjust the crushing and grinding equipment so as to prepare the bulk of the material in the grain size that appears likely under the circumstances to be most efficient.

SUMMARY

A study was made of the effects of size of particles on the properties and behavior of fertilizers during preparation and use. In the field tests nonsegregating fertilizers with grains ranging in size from 2- to 3-mesh to 80- to 150-mesh, and dry-mixed fertilizers with the superphosphate particles only varying in size, were applied accurately and uniformly to cotton in 3 soil types for 3 seasons in South Carolina. Of the grained fertilizers 80- to 150-mesh particles produced highest yields in a majority of the 13 trials. The smallest superphosphate particles were best in every test, and the average difference in yield as between the smallest and largest particles was alone more than enough to pay for all the fertilizer used. Chemical analyses were made on the soil to which the fertilizers had been applied to determine differences in leaching and change in solubility of the fertilizer elements. Laboratory tests were also made to determine the present range of particle size in typical fertilizers and the effects of particle size on various properties of fertilizers and their behavior during handling and distribution.

The average mixed fertilizer consists almost entirely of material that will pass through a 5-mesh and be held on a 200-mesh screen. No significant difference in the distribution of particle size exists between various classes of mixed fertilizers. Double superphosphates

[3] These probable errors have been corrected to eliminate as much as possible the variance due to factors other than particle size.

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appear to be composed of coarser particles on the average than ordinary superphosphates.

Small particles of fertilizer adsorb moisture from the air and tend to cake more readily than large ones.

Apparent density varies with the size distribution of fertilizer particles, and therefore the size of bag required to hold a given weight of substance depends upon its particle-size distribution.

Segregation of fertilizer mixtures is caused largely by differences in the sizes of the grains of the different components. Segregation occurs to a slight extent in most commercial mixtures during shipment and application to the soil. In most cases this is so slight as to be of little consequence, but in 1 of the 10 mixtures tested the composition changed seriously during distribution. Regrinding a segregating mixed fertilizer a little finer considerably reduces segregation.

Nitrogen, potash, and total soluble salts were found to be removed from the placement area in the soil in greater proportion as the size of the particles diminished. Nitrogen disappeared relatively much more rapidly than other soluble salts.

Decrease in the size of fertilizer particles containing phosphates was followed by greater reversion of P_2O_5 to insoluble forms in the loam soils and by disappearance of larger quantities of total P_2O_5 from the immediate zone of application in the coarse sand soil.

Large fertilizer particles in side placements under the conditions of this work slightly hastened emergence of plants and powdered fertilizers delayed it. When mixed with the soil below the seed all sizes usually found in commercial fertilizers delayed germination.

Finer than 80-mesh superphosphate grains applied in a band were decidedly superior to very coarse ones in increasing yields of cotton, but large grains of readily soluble nitrogenous materials were better in this respect than small particles of the same substance.

The most efficient particle size under the average circumstances encountered in this study with grained fertilizers was 80- to 150-mesh.

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THE COMPOSITION AND CONSTITUTION OF THE COLLOIDS OF CERTAIN OF THE GREAT GROUPS OF SOILS

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INTRODUCTION

In his classification of soils on the basis of field data Marbut (*12*) [1] recognizes the existence of great groups of soils. He and his coworkers in the Division of Soil Survey have determined the general geographical positions of five of these great groups in the United States by means of careful and detailed soil surveys. Of these, four are found in the humid portion of the country and belong in the Pedalfer division of soils. These are named Podzol, Gray-Brown Podzolic, Prairie, and Lateritic. This latter group is sometimes subdivided into the Red and Yellow soils. In the Pedocal division of soils the only great group which has been extensively studied in the field is the Chernozem group. In addition, the existence of Chestnut-Brown, Brown, and Gray-Desert soils is recognized. From foreign sources it is known that there exists another great group of soils known as the Laterites. These are sometimes subdivided into aluminous and ferruginous Laterites. No true Laterites are known to exist in the continental limits of the United States.

In 1931 Anderson and Byers (*2*) published a paper dealing with the characteristics of the collodial materials in the profiles of certain of these major groups. In 1932 Byers (*6*) discussed the constitution of

[1] Italic numbers in parentheses refer to Literature Cited, p. 38.

the hypothetical soil acids which were assumed to exist in the soil colloids and to be responsible for the characteristics of the great soil groups. In 1933 Brown, Rice, and Byers (*5*) presented the results of a study of claypan soils, belonging to the Prairie and Chernozem groups, in which was emphasized the uniformity of character of the colloid of not only the profile of a given soil type but also the close similarity of colloids derived from soils of closely similar types. This study was deemed to indicate within such groups the existence of a characteristic substance which is sufficiently dominant to make the resultant colloid material throughout the profile effectively one substance (not one compound). It is recognized, of course, that this substance must be impure, and also that the properties of the substance are the resultants of the properties of the individual compounds present.

In the paper by Anderson and Byers (*2*) and also in one by Brown and Byers (*4*) it is recognized that the uniformity of colloid composition within a soil profile does not always exist and diversity of composition is particularly marked in soils of the Podzol group. It therefore seemed worth while to make a study of the soils of the great groups which might be expected to differ widely from each other, in order to determine definitely some of these relationships. It also seemed possible by proper selection of typical representatives of each group to establish by analytical examinations the outstanding characteristics of each group.

For this purpose the Division of Soil Survey was requested to select the soil type which in its judgment best and most completely reflected the field characteristics of the major soil groups. The various inspectors of the Division most familiar with the respective groups were then asked to select and collect a profile sample which best presented the characteristics of the soil type which had been selected. To represent the Podzol group Mark Baldwin furnished the Au Train profile, later described. Baldwin also furnished the Miami silt loam as representative of the Gray-Brown Podzolic group. T. D. Rice furnished the Chernozem profile belonging to the Barnes series, also the Prairie profile of the Carrington series. W. E. Hearn furnished the profiles representing the Lateritic soils selected from the Cecil and Ruston soil series. Since no true Laterites exist in the United States, H. H. Bennett was requested to draw upon his knowledge of tropical soils and select a soil which as completely as possible would represent the aluminous Laterites. The soil selected, the Columbiana clay from Costa Rica, is not wholly satisfactory but is believed to be the best representative of its group obtainable in the Western Hemisphere. It was collected and shipped by the United Fruit Co.

To the above list was added a Podzol profile collected by H. E. Middleton and D. B. Lovejoy. It is the Caribou silt loam from Maine.

While the primary purpose of the investigation was, as above indicated, to find the chemical characteristics attendant upon the wide field differentiation of these soils, a very considerably increased scope developed as the study progressed. The description of each soil profile is given in conjunction with the results of analytical examinations.

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METHODS OF EXAMINATION

The soil samples when received were air dried and carefully subsampled. The subsamples for mechanical analysis were examined by the pipette method described by Olmstead, Alexander, and Middleton (*16*) on the basis of the oven-dry sample. The chemical analyses of the whole soil were made by the methods described by Robinson (*17*). The colloids were extracted by the process described by Brown and Byers (*4*). The centrifuge speed and rate of flow were governed to collect that portion of the fine material consisting of particles of 0.3-micron or smaller particle diameter. After separation by the Pasteur-Chamberland filter the colloids were air-dried on porous clay plates and were not heated above room temperature at any time until the process of analysis was undertaken. This point is somewhat important by reason of the bearing it has on the water relationships of these same samples. In considering the derived data of the tables the water of combination of the soil acids does not include any combined water which may be evolved by heating the samples to 105° C. The colloids were analyzed by the usual methods except that special care was exercised in securing duplicate analyses.

Special attention is directed to the tables of derived data given in the following tables. The figures given are calculated from the analytical data. The much-used and familiar ratios, the silica-sesquioxide, silica-alumina, and silica-iron oxide ratios, are obtained by dividing the percentage quantities of the components by their respective formula weights, and the quotients obtained are compared in the ratios. The ratios represent the relative formula weights of silica as compared with the corresponding quantities of the other components named in each ratio. In a similar manner the formula weight ratio of the ferric oxide and alumina indicates the relative formula weights of these components. The silica-total base ratios indicate the relative number of formula weights of silica to the sum of the formula weights of the calcium oxide, magnesium oxide, manganese oxide, potassium oxide, and sodium oxide in the colloid. In this bulletin manganese oxide is included for the reason that certainly a part, although an unknown portion, is present as replaceable manganese. In colloids derived from soils containing large quantities of concretionary manganese dioxide it seems probable that manganese may well be omitted from the silica-base relation.

It has long been customary to include in chemical soil analyses a quantity known as the "water of combination" which is defined as the precentage loss on ignition less organic matter and carbon dioxide from carbonates.

In the considerations involved in this bulletin the soil colloid is assumed to consist chiefly of one or more complex acids in which a portion of the hydrogen is replaced by metals. If therefore one wishes to gain information concerning the constitution of these hypothetical acids, it is necessary to add to the combined water the water equivalent of the bases present. Strictly speaking, since the colloids are amphoteric, the water equivalent of the acid radicals present ought also to be included. In this bulletin this has not been done because the acidic components present are so small that no essential change would result were they included. The water equivalent of

the bases is obtained by the calculation: Formula weight of base: percentage of base :: 18 : x. The sum of the values of x for the bases is added to the percentage of combined water. Since the colloid always contains organic matter and sometimes carbonates as well, the quantity obtained above is divided by 100 minus the percentage of organic matter and the calcium carbonate equivalent of the carbon dioxide present. The resulting number is the "water of combination of the soil acids." There are at least four inherent errors involved in these calculations: (1) The quantity of organic matter is not accurately determinable; (2) a portion of the bases is most certainly held by the organic matter; (3) a portion also of the bases may be present in unaltered parent material; and (4) a portion of the combined water of the soil may be lost in drying soils at 105° C. Despite these shortcomings the relationship so arrived at is most useful in considerations involving the relationship of the soil colloids to each other.

In order to bring the water of combination of the inorganic soil acid into a more usable relation to the other derived data, corresponding formula-weight ratios are calculated. Those given are the silica-water, water-alumina, and water-sesquioxide ratios. They are obtained by dividing the percentage quantities of combined water, plus the water-equivalents of the bases by the formula weight of water. The formula weight equivalents of water are then compared with the corresponding quotients obtained from the percentage quantities of silica, alumina, and ferric oxide.

THE BARNES LOAM PROFILE

The Pedocals are divided by Marbut (*12*) into four groups—Chernozem, Chestnut, Brown, and Gray. This classification is made on the basis of the color of the soil's surface horizon, which is determined by the quantity of organic matter present. A typical member of the Chernozem group is the Barnes. This soil and those related to it are dominant within the Chernozem belt of the Dakotas, and extend northward into Canada.

The sample of Barnes loam used in this investigation was taken 2 miles east of Le Bolt, S. Dak. It is considered typical of the Barnes group of soils.

The surface horizon is 9 inches in depth. It is black in color, due to the presence of organic matter. The second horizon extends from a depth of 9 to 17 inches. This layer is brown, containing less organic matter than the first. This is a transitional layer, as far as organic matter is concerned, between the black surface soil and the zone of carbonate accumulation, which extends from a depth of 17 to a depth of 33 inches. Beneath this zone of carbonate accumulation is the parent glacial drift, from which the soil has been derived. It is very calcareous. Above the zone of carbonate accumulation the soil does not effervesce with hydrochloric acid, although it undoubtedly contains minute quantities of carbonates or bicarbonates (*1*). In table 1 is shown the mechanical analysis of the Barnes soil profile samples.

TABLE 1.—*Mechanical analysis of Barnes loam (soil)*

Sample no.	Horizon	Depth	Fine gravel (2–1 mm)	Coarse sand (1–0.5 mm)	Medium sand (0.5–0.25 mm)	Fine sand (0.25–0.1 mm)	Very fine sand (0.1–0.05 mm)	Silt (0.05–0.005 mm)	Clay (0.005–0 mm)	Colloid[1] (0.002–0 mm)	Organic matter by H_2O_2
		Inches	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
10305	A	0– 9	1.8	3.8	6.0	14.3	10.3	25.0	33.0	26.7	5.4
10306	B_1	9–17	1.6	4.0	8.1	22.7	14.0	17.9	29.1	25.3	2.2
10307	B_2	17–33	1.3	3.1	4.5	10.0	7.5	24.4	48.4	35.6	.3
10308	C	33–60	2.7	6.1	6.4	9.7	7.6	25.4	41.2	31.5	.4

[1] Included in clay.

The decrease in the percentages of fine gravel, coarse sand, and medium sand in horizons A, B_1, and B_2 of the Barnes soil over the corresponding percentages in the parent material, horizon C, shows that the fragmentation is proceeding more rapidly in the former. The higher values for clay and colloid in layer 3 indicate a removal of colloid from the first and second layers and accumulation in the third. The parent drift has a higher percentage of colloid than either horizon A or B_1, but less than B_2 where the accumulation has taken place. The amounts of organic matter, as determined by the hydrogen peroxide method, during mechanical analysis, agree very well with the amounts as determined by the combustion method. Attention will be called later to these figures in table 2. The greater difference in the third horizon is due to the presence of calcium carbonate which interferes with the peroxide method.

TABLE 2.—*Chemical analysis of Barnes loam (soil)*

Sample no.	Horizon	Depth	SiO_2	Fe_2O_3	Al_2O_3	MgO	CaO	K_2O	Na_2O	TiO_2	MnO	SO_3	P_2O_5	Ignition loss	Total	Organic matter	CO_2 from carbonates
		Ins.	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
10305	A	0– 9	69.32	3.84	11.39	0.92	1.61	1.80	1.14	0.49	0.16	0.14	0.17	9.53	100.51	5.98	0.0
10306	B_1	9–17	73.56	3.96	11.31	.72	1.53	1.76	1.16	.49	.12	.11	.01	5.26	99.99	2.36	.0
10307	B_2	17–33	53.43	3.70	10.18	2.00	13.42	1.42	.84	.46	.15	.07	.18	14.48	100.33	1.12	10.50
10308	C	33–60	57.58	3.93	10.39	2.37	10.52	1.62	.89	.48	.18	.06	.15	12.02	100.19	.59	8.66

Table 2 shows the results of the chemical analyses of the four layers of the Barnes profile. The higher percentages of silica in horizons [2] A and B_1 over those of B_2 and C are due to two factors. The first of these is that the removal of the originally present calcium carbonate from the upper layers has increased, relatively, the percentages of the remaining constituents. The second factor is the leaching downward of the colloid, which has a lower percentage of silica than the soil as a whole, raising the percentage of silica in the remaining soil. The percentages of iron and aluminum oxides are essentially constant throughout the profile. The magnesium oxide percentage indicates the presence of dolomite in the third and fourth horizons, but shows that no accumulation has taken place in the third. On the other

[2] In considering the portions of the Chernozem and Prairie soils it is convenient at times to use the term "horizon." It is recognized, of course, that in these soils the profile development does not warrant the term. It is used for convenience only.

hand, the calcium oxide percentages show an accumulation in the third horizon, which is the defining characteristic of the pedocalic soils. The relatively high percentages of sodium and potassium oxides indicate the likelihood of considerable unweathered minerals. The factor titanium dioxide is not discussed in this or in any other soil because of ignorance of its role in the soil. The quantities of phosphorus pentoxide are so small that they have little bearing on the gross composition of either the soil or the soil colloid. The lack of carbonate carbon dioxide in horizons A and B_1 shows complete leaching of the original calcareous drift to a depth of 17 inches. The percentages of carbonate carbon dioxide in horizons B_2 and C indicate the quantities of calcium carbonate and of dolomite present in them. The same thing is shown by the calcium and magnesium oxide percentages already mentioned.

The colloidal material extracted in the manner described on page 3 was analyzed, and the results are shown in table 3. Excepting the values for organic matter and CO_2 from carbonates, the data indicate rather constant composition of soil colloid throughout the profile. The former reflects the higher percentages of organic matter near the surface and the latter the presence of lime carbonate below a depth of 17 inches in the colloidal fraction of the soil. It is noteworthy that most of the accumulated carbonate is not of colloidal size, or at least was not extracted as such. The relatively high percentages of magnesium oxide, potassium oxide, and sodium oxide indicate either one or two possibilities, namely, that there is present, even in the colloid, some mineral or minerals very resistant to hydrolysis, or that the colloid complex present has a very strong affinity for these bases. It is probable that the result is the effect of both factors. A comparison of the percentages of potassium in the soil with those in the colloid indicates that none of this constituent is lost from the soil during weathering conditions under which this soil was formed. This is not surprising in view of the limited rainfall. Since the sample came from a virgin area the problem of removal by crops does not enter.

TABLE 3.—*Chemical analysis of Barnes loam (colloid)*

Sample no.	Horizon	Depth	SiO_2	Fe_2O_3	Al_2O_3	MgO	CaO	K_2O	Na_2O	TiO_2	MnO	P_2O_5	Ignition loss	Total	Organic matter	CO_2 from carbonates	pH values
		Ins.	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	
10305	A	0- 9	45.90	9.96	19.12	2.28	1.81	1.70	0.02	0.68	0.163	0.39	18.34	100.36	10.12	0.0	6.9
10306	B_1	9-17	48.21	10.93	20.23	2.49	1.73	1.43	.13	.74	.147	.25	14.15	100.44	5.77	.0	7.1
10307	B_2	17-33	49.21	9.76	19.44	2.68	5.03	1.44	.06	.74	.096	.31	11.76	100.53	1.94	2.59	8.1
10308	C	33-60	50.29	9.50	19.32	2.96	4.34	1.40	.20	.68	.133	.24	10.93	99.99	1.03	2.46	8.2

Table 4 shows some data derived from the chemical analysis of the colloid. The ratios indicate constancy of composition. This means that in all four horizons the same material is being dealt with. It does not indicate, however, whether a single component is being dealt with or a mixture of constant composition. Although in general the constancy of composition may be taken as an indication of the presence of a single substance, more evidence is necessary in order to draw definite conclusions as to the existence of definite compounds. It

should be emphasized that the constancy of the ratios indicates nothing concerning the presence, or absence, of a single compound. This method of expression simply eliminates similarities or differences due to organic matter, carbonates, or other components not concerned with the components in question. Evidence of the presence of individual compounds would be directly furnished were methods available for purifications and for determination of molecular weights.

TABLE 4.—*Derived data: Barnes loam (colloid)*

Sample no.	Horizon	Depth	Molecular ratio								Combined water	Combined water of soil acid
			$\frac{SiO_2}{Fe_2O_3+Al_2O_3}$	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{Fe_2O_3}$	$\frac{Fe_2O_3}{Al_2O_3}$	$\frac{SiO_2}{\text{Total bases}}$	$\frac{SiO_2}{H_2O}$	$\frac{H_2O}{Al_2O_3}$	$\frac{H_2O}{Fe_2O_3+Al_2O_3}$		
		Inches									*Pct.*	*Pct.*
10305	A	0–9	3.05	4.07	12.22	0.333	6.96	1.21	3.36	2.52	8.22	11.34
10306	B_1	9–17	3.00	4.04	11.68	.346	7.13	1.30	3.11	2.31	8.38	11.03
10307	B_2	17–33	3.25	4.29	13.35	.321	7.10	1.46	2.94	2.23	7.23	10.09
10308	C	33–60	3.36	4.41	14.04	.314	7.27	1.50	2.94	2.24	7.45	9.99

Careful examination of some of the ratios yields some information on the processes of soil formation. It was pointed out on page 5 that the first two layers or horizons have the same mechanical composition; that the third horizon shows an accumulation of colloid from the upper two horizons and hence is a mixture of horizons A and B, and the colloid from the parent material. The colloid from horizon C represents the parent drift where the influence of soil-forming processes, as distinguished from hydrolysis, have not reached. Horizons A and B_1 represent the soil colloid as modified by the soil-forming processes. Horizon B_2 should be intermediate in composition and properties. The silica-sesquioxide ratio of horizons A and B_1 averages 3.02; that of the parent colloid, 3.36; that of horizon B_2, intermediate, 3.25, with the influence of the parent material predominating as would be expected from the mechanical analysis. The silica-alumina ratio and the silica-iron oxide ratios indicate that this increase in the ratio of silica to sesquioxide is true of both alumina and iron, but more pronounced with the former. It has been pointed out by Brown, Rice, and Byers (*5*) that the iron present in the Chernozem type soils must be regarded as combined with silica. The ratios of silica to the combined water of the soil acid shows a steady increase from horizon A to horizon C, or if the reciprocal of this ratio be taken it is found that the ratio of water to silica is greater in the colloid of the surface layers than in that of the parent drift colloid. Likewise, the combined water-sesquioxide ratio shows a higher degree of hydration at the surface than at the greater depth.

These departures from constancy are very interesting because they bear on the question of weathering processes. From the trend of the silica-sesquioxide ratios it may be inferred that the weathering processes are such that some silica is lost from the colloid during weathering. The variations noted in the combined water-silica ratios and the water-sesquioxide ratios indicate that the more weathered the colloid is the more highly hydrated it is with respect to both silica and

sesquioxide. It may be noted here, however, that one would expect, from the behavior of aluminum and iron hydroxides and of silicic acids that some irreversible dehydration (*5*) should take place at the surface where the forces of wetting and drying, and of heat, are most active.

THE CARRINGTON LOAM PROFILE

The Prairies are grassland soils developed under conditions of moderately high rainfall. They are similar to the Chernozems in that both are grassland soils high in organic matter. The Carrington loam is a typical member of this group. Both of these soils have been developed from calcareous glacial drift. The profile of the Carrington is acid in reaction excepting the parent glacial drift, whereas the Barnes is either neutral or alkaline throughout. Along the streams soil-forming processes have produced Gray-Brown Podzolic, Red, or Yellow soils. Indeed, the Prairie soils themselves have been podzolized to a very limited extent.

The profile used in this study was the Carrington loam, collected in Buchanan County, Iowa, 1 mile southwest of the town of Winthrop. The profile is described as follows:

Horizon A_1, 0 to 3 inches. This material is a very dark grayish-brown, loose, mellow, granular loam and contains much silt. It forms a turf loosely held by grass roots.

Horizon A_2, 3 to 13 inches. A very dark grayish-brown fine loam, made up of granules, mostly fine.

Horizon B_1, 13 to 22 inches. This is a transition layer ranging in color from very dark in the upper portion to brown in the lower. It represents the zone of transition from the surface soil to the subsoil. It is imperfectly granular in the upper portion and structureless in the lower.

Horizon B_2, 22 to 43 inches. This is a brown loam, slightly heavier in texture than the layers above. There is no carbonate present.

Horizon B_3, 43 to 70 inches. Brown clay loam splotched with yellow and rust brown, streaked by occasional dark tongues. A few boulders and gravel present. This is the partially decomposed parent drift, leached of its carbonates.

Horizon C, 70 to 80 inches. Yellowish-brown clay loam with lumps of heavy clay. There are faint colorings of gray and rust brown. This material is the weathered, but unleached, calcareous drift of Iowan age. The area from which the sample was taken had not been cultivated.

Table 5 shows the mechanical composition of the Carrington loam profile. Taken as a whole, the profile shows very little variation in texture. In the upper horizons the coarser material has broken down to give finer particles. A slight accumulation of clay in the fourth

TABLE 5.—*Mechanical analysis of Carrington loam*

Sample no.	Horizon	Depth	Fine gravel (2-1 mm)	Coarse sand (1-0.5 mm)	Medium sand (0.5-0.25 mm)	Fine sand (0.25-0.1 mm)	Very fine sand (0.1-0.05 mm)	Silt (0.05-0.005 mm)	Clay (0.005-0 mm)	Colloid (0.002-0 mm)	Organic matter by H_2O_2	pH
		Inches	*Per-cent*	*Per-cent*	*Per-cent*	*Per-cent*	*Per-cent*	*Per-cent*	*Per-cent*	*Per-cent*	*Per-cent*	
10082	A_1	0- 3	1.1	5.8	7.7	10.5	7.7	34.8	26.5	21.2	5.4	5.5
10083	A_2	3-13	1.2	6.2	7.8	10.1	6.6	36.2	27.8	22.5	3.8	5.2
10084	B_1	13-22	2.1	6.3	7.6	10.2	7.7	34.2	29.3	24.5	2.1	4.9
10085	B_2	22-43	2.2	7.3	9.6	14.1	11.4	23.7	30.4	26.2	1.0	5.1
10086	B_3	43-70	2.7	7.5	9.5	14.5	11.5	24.8	28.8	23.8	.4	6.4
10087	C	70-84	3.1	8.7	10.2	14.9	11.6	24.7	26.2	11.0	.4	8.1

horizon accounts for the heavier texture noted by the collector in the description of the sample. Given in this table also are the values found by the peroxide method for the organic matter. They correspond nicely to those given in table 6 by the combustion method. The principal point of interest in this table is that it shows the mechanical movement of colloid downward has been very small. This is in contrast to some of the soils to be considered later, in which the movement of the finer particles downward is the principal soil-forming process. The heavy cover of grass and the presence of the root mat have been an important factor in preventing this movement. In some grassland soils there is marked accumulation of colloid in subsurface layers (*1*, *2*, *3*, *4*, *5*).

TABLE 6.—*Chemical analysis of Carrington loam (soil)*

Sample no.	Horizon	Depth	SiO_2	Fe_2O_3	Al_2O_3	MgO	CaO	K_2O	Na_2O	TiO_2	MnO	P_2O_5	SO_3	Ignition loss	Total	Organic matter	CO_2	N	pH
		Ins.	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	
10082	A_1	0- 3	74. 62	3. 12	9. 72	0. 60	0. 99	1. 53	0. 74	0. 54	0. 08	0. 11	0. 04	8. 25	100. 34	5. 57	0. 0	0. 29	5. 5
10083	A_2	3-13	75. 69	3. 33	10. 50	.49	.96	1. 53	.81	.60	.10	.10	.03	6. 27	100. 41	3. 43	.0	.17	5. 2
10084	B_1	13-22	76. 25	3. 62	11. 28	.65	.69	1. 54	.81	.60	.08	.07	.05	4. 80	100. 44	1. 98	.0	.12	4. 9
10085	B_2	22-43	76. 95	4. 07	11. 36	.81	.62	1. 45	.68	.60	.06	.07	.04	3. 66	100. 37	.75	.0	.05	5. 1
10086	B_3	43-70	77. 66	3. 96	11. 05	.68	1. 06	1. 52	.79	.54	.07	.06	.05	2. 98	100. 42	.34	.0	.03	6. 4
10087	C	70-84	75. 49	3. 55	10. 02	.99	2. 81	1. 52	.77	.49	.05	.04	.12	4. 42	100. 27	.00	2. 70	.02	8. 1

In table 6 are shown the results of the chemical analysis of the Carrington loam profile. The profile has an extreme degree of constancy of composition with respect to the major constituents. This is characteristic of the Prairie profiles. The unleached calcareous drift is indicated by the higher percentage of calcium oxide in the sixth horizon. Little if any of the 2.7 percent of carbonate carbon dioxide is present as dolomite, as shown by the magnesium oxide figures. The organic matter content and distribution is normal for a Prairie soil. The remaining constituents vary so little that they require no comment. The pH values for the first four horizons are all distinctly acid. As is usual, the upper layer is a little less acid than those immediately lower because of the bases combined with the organic matter. Due to the presence of unleached carbonates horizon C is basic, while horizon B_3 is intermediate in acidity between horizons B_2 and C. The calcium carbonate originally in horizon B_3 has been removed, but apparently exchangeable calcium remains sufficient to reduce the acidity shown by the upper horizons.

Table 7 gives the chemical analysis of the colloids extracted from the six horizons of the Carrington loam. The percentages of magnesium oxide, sodium oxide, titanium oxide, manganese oxide, and phosphorus pentoxide remain essentially constant throughout when the effect of the organic matter on them is considered. The percentage of calcium oxide in the first horizon is higher than in the horizons underneath it except the sixth. Calcium is an important mineral constituent of the grasses and the accumulation may be attributed to the decayed grass residues. Whether it is a part of the organic or inorganic portions of the colloid is not known.

TABLE 7.—*Chemical analysis of Carrington loam (colloid)*

Sample no.	Horizon	Depth	SiO_2	Fe_2O_3	Al_2O_3	MgO	CaO	K_2O	Na_2O	TiO_2	MnO	P_2O_5	Ignition loss	Total	Organic matter	CO_2	N
		Ins.	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
10082	A_1	0– 3	41.12	10.36	20.90	1.52	1.31	1.44	0.12	0.62	0.10	0.37	22.56	100.42	12.92	0.0	----
10083	A_2	3–13	41.84	10.09	23.22	1.61	.97	1.38	.04	.55	.14	.36	20.18	100.38	9.94	.0	----
10084	B_1	13–22	43.82	10.67	24.34	1.71	.94	1.31	.06	.68	.09	.28	16.47	100.37	6.16	.0	----
10085	B_2	22–43	44.77	12.92	24.67	1.71	1.02	1.63	.01	.82	.08	.26	12.41	100.30	2.53	.0	----
10086	B_3	43–70	45.42	13.69	24.30	1.81	1.14	1.85	.05	.87	.07	.29	10.77	100.26	1.14	.0	----
10087	C	70–84	45.42	13.77	23.82	1.79	1.48	1.89	.13	.82	.08	.22	10.93	100.35	1.07	.10	----

The increase in calcium oxide in horizon C is due to the presence of a small quantity of calcium carbonate. It is worthy of note that although the parent material contained considerable quantities of carbonates, very little is in the colloidal form. This was not the case with the Barnes, where 2.5 percent of carbonate carbon dioxide was present in the colloid from the parent material. Carbonates must have been present in the colloid of the parent material of the Carrington, also, but due to the higher rainfall most of the fine particles of carbonates have been leached at 70 to 84 inches. In the Barnes this was not true at a depth of 17 to 33 inches. The relatively high percentages of potassium oxide indicate considerable unweathered mineral or an acid complex strong in its affinity for potassium. The low percentage of sodium oxide indicates that all of the sodium has been leached out. There are still sodium minerals in the coarse fraction as indicated by the percentage shown in the soil in table 6. The organic matter is rather concentrated in the colloidal fraction as there is more than twice as much in the colloid as in the soil. Organic matter exists at considerable depth, there being 1 percent in colloid of horizon C. Consideration of the silica, alumina and iron oxide percentages is facilitated by use of the derived data in table 8.

TABLE 8.—*Derived data: Carrington loam (colloid)*

Sample no.	Horizon	Depth	Molecular ratio							Combined water	Combined water of the soil acid
			$\frac{SiO_2}{Fe_2O_3+Al_2O_3}$	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{Fe_2O_3}$	$\frac{Fe_2O_3}{Al_2O_3}$	$\frac{SiO_2}{\text{Total bases}}$	$\frac{SiO_2}{H_2O}$	$\frac{H_2O}{Al_2O_3}$	$\frac{H_2O}{Fe_2O_3+Al_2O_3}$		
		Inches									*Per-cent*	*Per-cent*
10082	A_1	0– 3	2.53	3.33	10.52	0.317	8.54	0.966	3.45	2.63	9.64	12.71
10083	A_2	3–13	2.39	3.06	10.98	.278	8.72	.964	3.17	2.48	10.24	12.96
10084	B_1	13–22	2.38	3.05	10.88	.281	9.64	1.052	2.90	2.26	10.31	12.44
10085	B_2	22–43	2.30	3.08	9.18	.335	9.34	1.151	2.68	2.00	9.88	11.61
10086	B_3	43–70	2.33	3.17	8.78	.361	8.69	1.198	2.65	1.94	9.63	11.32
10087	C	70–84	2.36	3.23	8.74	.370	8.02	1.155	2.80	2.04	9.92	11.74

Table 8 contains data derived from the figures shown for the composition of the colloid of the Carrington profile in table 7. The silica-sesquioxide and silica-alumina ratios are essentially constant. The silica-iron oxide ratios are indicative of slight accumulation of iron in the upper horizons. That is to say, the silica has been leached downward or dissolved to a greater extent than has the iron. The

ratio of silica to total bases is fairly constant and rather high. The ratio of iron oxide to alumina indicates a more rapid removal of alumina than of iron oxide from the surface. The combined water of the soil acid, while in general uniform, shows a definite decrease with depth. This trend is also shown by the water-alumina and water-sesquioxide ratios.

The composition of the colloid from the six horizons of the Carrington is constant with respect to all of the constituents excepting combined water and organic matter. The sum of these two constituents constitutes the ignition loss. The combined water of the soil acid and the organic matter show a continual decrease from top to bottom of the profile.

The ignition loss is made up of three factors, (1) the combined water, (2) organic carbon, and (3) the hydrogen, oxygen, and nitrogen of the organic matter. Of these only the organic carbon may be accurately determined. In these analyses the organic matter has been calculated on the basis of 58-percent carbon content (using the Wolf factor $0.471 \times CO_2$). In many investigations of fractions of soil organic matter (*1*) from soils the carbon content has usually been found to be much lower than 58 percent. If in this profile the carbon content be assumed to be 45 percent the combined water becomes very nearly constant. If, therefore, the organic matter is uniformly low, as the quantity of it increases toward the surface of the profile, the combined water and therefore the combined water of the soil acid, appears larger than it really is. Unfortunately in other profiles this assumption does not suffice to eliminate variations in the water relations. It is possible also that at the surface the colloid may be more fully hydrated but this assumption does not seem logical in view of the fact that a normally wetter condition must be assumed in the subsoil than in the surface portion of the soil. There is also the probability that some of the higher base content of the surface colloid is associated with the organic matter. The increase of bases with depth is not sufficient to indicate a large quantity of unweathered colloid in the lower portion of the profile. This source of variation of the combined water of the soil acid will be stressed in the discussion of the Miami profile (p. 14).

THE MIAMI SILT LOAM PROFILE

The Miami soils occur in large areas in western Ohio and central and northern Indiana and southern Michigan. They are typical of the Gray-Brown Podzolic group as it occurs west of the Appalachian region. The sample used in this study was taken in Grant County, Ind., on a gentle upland slope in a section of undulating till plain, which has been mildly dissected. The drainage is good. The vegetation consists of hard maple, linden, and white oak. The land has never been cleared or plowed. The ground cover is a very thin scattering of grass and weeds.

The A_1 horizon is a very dark brownish-gray silt loam high in organic matter. It is 1½ inches thick and is overlain by a very thin leaf litter. The A_1 horizon is underlain by a transition layer 1 inch thick. This layer was not sampled because it is a mixture of the A_1 horizon with the A_2 horizon, brought about by the penetration of the A_1 into the A_2 through the paths of burrowing insects and worms.

The A_2 horizon extends from a depth of 2½ inches to a depth of 9 inches. It is light brownish-gray, friable, silt loam, definitely platy. Underneath this layer is a 2-inch transition layer which was not sampled.

The B horizon extends from a depth of 11½ inches to a depth of 23½ inches. It is a heavy, brown plastic silty clay with definite blocky structure.

Following the B horizon is a 4-inch transition layer which was not sampled. The C horizon consists of rather hard, medium-textured, calcareous till of late Wisconsin age. The layer extends from 27 to 48 inches.

Table 9 gives the mechanical analysis of the Miami silt loam.

TABLE 9.—*Mechanical analysis of Miami silt loam* [1]

Sample no.	Horizon	Depth	Fine gravel (2–1 mm)	Coarse sand (1–0.5 mm)	Medium sand (0.5–0.25 mm)	Fine sand (0.25–0.1 mm)	Very fine sand (0.1–0.05 mm)	Silt (0.05–0.005 mm)	Clay (0.005–0 mm)	Colloid (0.002–0 mm)	Organic matter by H_2O_2
		Inches	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
10341	A_1	0 – 1½	0.1	2.1	3.5	6.4	6.0	46.0	29.7	18.1	6.0
10342	A_2	2½– 9	.1	2.0	3.5	6.4	5.7	47.0	32.5	20.2	2.5
10343	B	11½–23½	.0	1.4	2.1	4.8	4.8	25.1	60.6	50.6	.7
10344	C	27 –48	.1	2.8	2.9	6.0	6.5	38.2	42.9	31.0	.3

[1] Determinations by H. W. Lakin and T. M. Shaw.

The mechanical composition does not vary significantly except in the colloid and clay fractions. The accumulation of clay in the B horizon is typical of the podzolic soils. It is noted that the percentages of clay and colloid in the parent material (C horizon) is higher than in the A_1 and A_2 but lower than in the B because the colloid has been carried downward during the weathering process and in part has stopped in the B horizon. The percentages of organic matter removed by the hydrogen peroxide treatment, preliminary to mechanical analysis, agree fairly well with the percentages of organic matter shown in table 10.

The chemical analysis of the Miami silt loam soil is shown in table 10. The high percentages of silica in the A_1 and A_2 horizons reflect

TABLE 10.—*Chemical analysis of Miami silt loam (soil)* [1]

Sample no.	Horizon	Depth	SiO_2	Fe_2O_3	Al_2O_3	MgO	CaO	K_2O	Na_2O	TiO_2	MnO	P_2O_5	SO_3	Ignition loss	Total	Organic matter	N	pH
		Inches	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	
10341	A_1	0 – 1½	72.32	2.75	9.63	0.66	1.26	2.11	0.87	0.75	0.13	0.11	0.13	9.56	100.28	7.19	0.32	7.0
10342	A_2	2½– 9	75.49	2.95	10.58	.70	.76	2.25	.87	.78	.10	.11	.07	5.25	99.91	2.79	.16	6.4
10343	B	11 –24	64.29	6.52	16.54	1.66	.90	3.16	.73	.71	.12	.14	.06	5.73	100.56	.83	.09	6.3
10344	C	28 –48	47.48	4.30	11.39	4.78	12.59	2.48	.66	.53	.09	.11	.09	15.86	100.36	.34	.06	7.9

[1] Determinations by G. Edgington.

the large quantity of silt shown by the mechanical analysis, since the silt is principally silica. The accumulation of iron oxide and aluminum oxide in the B horizon is due to the higher percentage of these two constituents in the colloid, which has accumulated in this layer.

The high percentages of calcium oxide and magnesium oxide in the C horizon, together with the carbonate carbon dioxide present, indicate the presence of calcium carbonate and magnesium carbonate, probably as dolomitic limestone. The high percentages of potassium and sodium oxides indicate considerable unweathered mineral. The percentages of titanium dioxide, manganous oxide, phosphorus pentoxide, and sulphur trioxide are not indicative of anything unusual. The higher ignition losses in the A_1 and C horizons reflect the organic content of the A_1 horizon and the carbonate content of the C horizon. The hydrogen-ion concentration is normal for this type of soil. The more basic reaction at the surface horizon is due to the presence of base exchange calcium in this layer. That of the C horizon is due to presence of carbonates of calcium and magnesium.

The chemical analysis of the colloids extracted from the four horizons of the Miami silt loam are shown in table 11. The percentages of

TABLE 11.—*Chemical analysis of Miami silt loam (colloid)*

Sample no.	Horizon	Depth	SiO_2	Fe_2O_3	Al_2O_3	MgO	CaO	K_2O	Na_2O	TiO_2	MnO	P_2O_5	SO_3	Ignition loss	Total	Organic matter	N
		Inches	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
10341	A_1	0 – 1½	44.86	7.40	22.04	1.67	1.71	2.98	0.29	1.05	0.22	0.51	----	17.78	100.51	10.20	0.86
10342	A_2	2½– 9	47.46	7.94	22.98	1.39	1.20	2.90	.22	.70	.12	.40	0.22	14.90	100.43	6.82	.53
10343	B	11 –24	47.07	11.50	23.38	2.09	.96	4.37	.24	.67	.09	.33	.12	9.45	100.27	1.68	.19
10344	C	28 –48	46.13	10.66	22.97	2.14	[1] 2.65	4.25	.22	.60	.08	.37	.17	9.53	99.77	1.63	.18

[1] 1.62 CO_2=2.05 $CaCO_3$.

silica and alumina are essentially constant throughout the profile, that of iron oxide, however, increases in the B horizon and drops off again in the C horizon. This iron oxide accumulation in the B horizon is characteristic of the podzolic profiles. It will be noted that a considerable portion of the iron oxide presumably present in the original colloid has been leached from the A_1 and A_2 horizons. The increase in calcium oxide in the C horizon, together with its carbon dioxide content, indicates the presence of calcium carbonate of colloidal dimensions in the parent drift. The high percentages of potassium oxide in the B and C horizons may be taken to indicate a low degree of weathering with respect to the potassium minerals in these horizons. The sodium content is low throughout the colloid of all the horizons; this indicates that the sodium is probably leached out before it is fragmented to colloidal dimensions. The percentages of titanium dioxide, manganous oxide, phosphorus pentoxide, and sulphur trioxide are not significant in this study of the gross composition of the colloid. The percentage of organic matter indicates a wide distribution of particle size in this soil, there being relatively small increase of organic matter in the colloid fraction as compared with the whole soil.

Table 12 shows the derived data from the chemical analysis of the colloid of the Miami silt loam. The silica-sesquioxide ratios show a decrease in the B horizon as compared with A_1 and A_2. That this is chiefly owing to transfer of iron from the A to the B horizon is shown by the nearly constant values of the silica-alumina ratios in the profile and the relative increase of iron oxide shown by the silica-iron oxide and iron oxide-alumina ratios. These relations indicate that a part of the iron, at least, is present uncombined with the silica

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complex. The silica-total base ratios are low in general and yet indicate considerable leaching from the A_2 horizon. The relatively low values of the silica-base ratio in the A horizons indicates probable exchangeable bases associated with the organic matter. The silica-water, water-alumina, and water-sesquioxide ratios all show a remarkable constancy throughout the solum proper but alter rather sharply in the C horizon. The silica-sesquioxide and silica-alumina ratios in this colloid are higher in the Miami colloid than in the Carrington and the combined water of the soil acid is lower (table 8). These relations, together with the exceptionally high content of potassium (table 11), may be taken to indicate a relatively low degree of hydrolysis of the soil minerals associated with a high degree of maturity of profile characteristics. In so far as unweathered material is present in the colloid, particularly if that unweathered material is feldspathic, it should raise the silica ratios and lower the water content of the soil acid. (See also p. 28.)

TABLE 12.—*Derived data: Miami silt loam (colloid)*

Sample no.	Horizon	Depth	Molecular ratio								Combined water	Combined water of soil acid
			$\frac{SiO_2}{Fe_2O_3+Al_2O_3}$	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{Fe_2O_3}$	$\frac{Fe_2O_3}{Al_2O_3}$	$\frac{SiO_2}{\text{Total bases}}$	$\frac{SiO_2}{H_2O}$	$\frac{H_2O}{Al_2O_3}$	$\frac{H_2O}{Fe_2O_3+Al_2O_3}$		
		Inches									*Per-cent*	*Per-cent*
10341	A_1	0 – 1½	2.84	3.45	16.1	0.214	6.70	1.40	2.46	2.03	7.58	10.68
10342	A_2	2½– 9	2.87	3.50	15.9	.220	8.60	1.46	2.40	1.96	8.08	10.44
10343	B	11 –24	2.60	3.41	10.9	.314	6.49	1.42	2.41	1.83	7.77	10.11
10344	C	28 –48	2.63	3.41	11.5	.296	6.79	1.66	2.05	1.58	6.28	8.46

THE RUSTON LOAMY SAND PROFILE

The Ruston soils belong to the Red soils of the coastal plains. They have developed from unconsolidated sand and clay material, identical in character with that from which the Norfolk soils have developed. They have developed, however, in areas where the relief is stronger because of more thorough dissection by the existing cycle of erosion. The ground-water level stands well below the surface. The drainage for a long time has been good, and oxidation has been sufficient to give to these soils a reddish color in the B horizon. The A horizon is essentially identical in character with the Norfolk soils. The Ruston soils occur mainly in Alabama, Mississippi, and Louisiana. They have reached their normal stage of profile development. The profile used in this study is a loamy sand, collected 8 miles west of Cuthbert, Ga. The terrain is rolling to hilly and exceptionally well drained.

The A horizon is a brownish to yellowish gray, grading into yellowish-red loamy sand. It extends to a depth of 14 inches. The B horizon, extending from 14 to 40 inches, is a yellowish-red, friable sandy clay. The C horizon, or parent material, was collected to a depth of 60 inches. It is mottled and streaked light-red, yellow, and grayish-yellow sandy clay material.

Table 13 shows the mechanical analysis of the Ruston profile just described. The significant fact pointed out by the data is the almost

complete removal of the colloid from the A horizon and its accumulation in the B. This is brought about by the process of podzolization. The organic-matter content, as indicated by the hydrogen peroxide method, is very low.

TABLE 13.—*Mechanical analysis of Ruston loamy sand* [1]

Sample no.	Horizon	Depth	Fine gravel (2–1 mm)	Coarse sand (1–0.5 mm)	Medium sand (0.5–0.25 mm)	Fine sand (0.25–0.1 mm)	Very fine sand (0.1–0.05 mm)	Silt (0.05–0.005 mm)	Clay (0.005–0 mm)	Colloid (0.002–0 mm)	Organic matter by H_2O_2
		Inches	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
161	A	0–14	5.7	22.0	20.2	24.3	6.8	10.7	9.2	7.3	0.7
162	B	14–40	3.3	14.1	10.3	13.0	9.0	11.4	38.6	37.4	0.1
163	C	40–60	3.3	18.2	14.3	15.6	8.2	8.0	32.2	29.6	0.0

[1] Determinations by H. W. Lakin and T. M. Shaw.

Table 14 gives the chemical analysis of the three horizons of the Ruston profile under consideration. The high percentages of silica, due to the sandy nature of this soil, cause the relative changes in the other components. It may be noted, however, that the soil, on the basis of gross composition, is much lower in iron oxide and alumina than the soils heretofore considered. The thorough leaching to which the soil has been subjected is indicated by the low content of bases. Practically all these have been removed from this soil. The ignition loss and organic matter are also low. It is also true that the hydrogen-ion concentration is much lower than in the soils previously studied. There is no carbonate, either accumulated or residual, in the profile.

TABLE 14.—*Chemical analysis of Ruston loamy sand (soil)* [1]

Sample no.	Horizon	Depth	SiO_2	Fe_2O_3	Al_2O_3	MgO	CaO	K_2O	Na_2O	TiO_2	MnO	P_2O_5	SO_3	Ignition loss	Total	Organic matter	N	pH
		Ins.	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
161	A	0–14	87.28	2.40	4.78	0.04	0.36	0.24	0.17	1.14	0.10	0.07	0.21	3.35	100.14	1.85	0.04	4.8
162	B	14–40	75.61	5.29	12.82	.12	.07	.29	.03	.75	.05	.05	.01	5.04	100.13	.50	.04	4.9
163	C	40–60	81.02	3.36	11.23	.09	.09	.30	.06	.56	.03	.05	.02	3.73	100.54	.21	.02	4.8

[1] Determinations by G. Edgington.

Much more information can be gained by a study of the chemical composition of the colloid than by a study of that of the whole soil. Table 15 shows the chemical composition of the colloidal material extracted from the three horizons of the Ruston loamy sand. These three colloids have compositions which are remarkably constant. The most significant difference is in the organic matter, which is of course higher in the surface layer. It would seem that the soil-forming process in the case of the Ruston is primarily dependent only on two things—the organic life in the surface layer and the mechanical movement downward of the finer fraction, especially the colloid. The colloid apparently has undergone little chemical change during the soil-forming period.

TABLE 15.—*Chemical analysis of Ruston loamy sand (colloid)*

Sample no.	Horizon	Depth	SiO_2	Fe_2O_3	Al_2O_3	MgO	CaO	K_2O	Na_2O	TiO_2	MnO	P_2O_5	SO_3	Ignition loss	Total	Organic matter	N
		Ins.	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
161	A	0–14	37.16	12.81	31.30	0.23	0.46	0.79	0.29	0.93	0.10	0.17	0.12	16.87	101.23	4.53	0.29
162	B	14–40	36.59	12.70	32.57	.26	.43	.70	.35	.99	.07	.20	.09	15.36	100.31	2.55	.14
163	C	40–60	38.49	12.08	33.87	.27	.43	.74	.41	.98	.04	.16	.10	13.37	100.94	1.27	.12

The derived data for the Ruston colloid are shown in table 16. The ratios are all so constant that little comment is necessary. The various silica ratios indicate some translocation of iron oxide to the B horizon and an alteration of the iron-alumina ratios. The combined water of the soil acid is sensibly higher in the solum proper. The latter indicates, possibly, inaccuracy of organic-matter determinations.

TABLE 16.—*Derived data: Ruston loamy sand (colloid)*

Sample no.	Horizon	Depth	Molecular ratio								Combined water	Combined water of soil acid
			$\frac{SiO_2}{Fe_2O_3+Al_2O_3}$	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{Fe_2O_3}$	$\frac{Fe_2O_3}{Al_2O_3}$	$\frac{SiO_2}{\text{Total bases}}$	$\frac{SiO_2}{H_2O}$	$\frac{H_2O}{Al_2O_3}$	$\frac{H_2O}{Fe_2O_3+Al_2O_3}$		
		Ins.									*Pct.*	*Pct.*
161	A	0–14	1.60	2.01	7.71	0.261	21.8	0.866	2.32	1.84	12.34	13.46
162	B	14–40	1.53	1.90	7.66	.249	21.7	.823	2.32	1.85	12.81	13.67
163	C	40–60	1.57	1.93	8.47	.227	21.7	.913	2.11	1.72	12.10	12.79

THE CECIL SANDY CLAY LOAM PROFILE

The Cecil and related soil series are dominant in the piedmont region extending from Virginia southward to Georgia and Alabama. The two principal types are the sandy loam and the clay loam. Most of the area mapped as the latter is a sandy loam with the A horizon removed by erosion, exposing the B horizon which is high in clay. Some of the clay loams are, however, not eroded but derived from crystalline rocks low in quartz. Cecil soils are derived from granites, gneisses, and schists. The parent material of the soils is the partially weathered decomposition products of these rocks.

The profile used in this study was obtained on the erosion station at Statesville, N. C., and was taken near the sample described by Middleton, Slater, and Byers (*14*). In this case, however, the C horizon was taken, in addition to the samples of A_1, B_1, and B_2 used by the investigators just mentioned. The profile may be described as follows (*14, pp. 7–8*):

From 0 to 6 inches, the A horizon of light-brown sandy loam containing very little organic matter but more than either horizon B_1 or B_2. From 6 to 32 inches, the B_1 horizon, is a red clay loam which is very uniform in character. From 32 to 60 inches, the B_2 horizon of red clay loam with brown mottlings. This material is very compact when exposed and has a tendency to crack.

The C horizon consists of completely disintegrated schist in numerous narrow bands of various colors. It is pervious to water and has been extensively hydrolyzed and leached.

Table 17 gives the mechanical analysis of the Cecil profile. If one examines carefully the percentages of sand in the four horizons, it will be seen that the sands have remained undisturbed during the soil-forming process. The silt, however, has moved downward and accumulated in the B_2 horizon. The colloid and clay fractions have likewise moved downward, but they have accumulated to a greater extent in the B_1. These inferences are drawn assuming that the parent material was uniform in texture.

TABLE 17.—*Mechanical analysis of Cecil sandy clay loam (soil)*

Sample no.	Horizon	Depth	Fine gravel (2-1 mm)	Coarse sand (1–0.5 mm)	Medium sand (0.5–0.25 mm)	Fine sand (0.25–0.1 mm)	Very fine sand (0.1–0.05 mm)	Silt (0.05–0.005 mm)	Clay (0.005–0 mm)	Colloid (0.002–0 mm)	Organic matter by H_2O_2
		Inches	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
9415	A	0- 6	2.8	7.4	8.6	16.3	10.2	15.2	38.1	30.6	1.0
9416	B_1	6–32	1.7	3.6	4.5	9.6	7.2	14.5	58.4	55.7	.2
9417	B_2	32–60	1.3	2.8	3.0	6.9	7.6	21.9	56.4	50.8	.0
9418	C	60–84	.2	5.0	4.2	8.9	8.5	21.1	51.8	44.2	.1

Table 18 shows the chemical analysis of the Cecil profile. The hydrogen-ion concentration of these samples indicates a rather acid soil. The acidity of the first two layers is tempered somewhat by the presence of calcium, as will be seen in table 19. That the percentage of silica should dominate the analysis of the A horizon is to be expected from the sandy nature of this layer as indicated by the mechanical analysis. The figures for iron oxide and alumina indicate the movement downward of the colloidal complex, as was also shown by the mechanical analysis. The bases are all low, but especially so in the lower horizons. The titanium percentages are normal. The ignition loss is principally due to combined water. The figures for organic matter are low in comparison with the soils of other great groups so far considered.

TABLE 18.—*Chemical analysis of Cecil sandy clay loam (soil)*

Sample no.	Horizon	Depth	SiO_2	Fe_2O_3	Al_2O_3	MgO	CaO	K_2O	Na_2O	TiO_2	MnO	P_2O_5	Ignition loss	Total	Organic matter	CO_2 from carbonates	pH values
		Ins.	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	
9415	A	0- 6	74.66	4.95	12.33	0.05	0.24	[1] 0.57	[1] 0.24	1.30	0.27	0.16	7.09	101.86	2.44	0.0	4.9
9416	B_1	6–32	55.92	11.17	22.37	.04	.20	[1] .47	[1] .17	1.49	.05	.15	9.28	101.31	.34	.0	4.8
9417	B_2	32–60	52.04	12.56	24.19	.16	.16	[1] .35	[1] .19	1.37	.05	.16	9.99	101.15	.12	.0	4.6
9418	C	60–84	54.50	11.27	23.05	[2]	.07	.34	.01	1.69	.10	.11	8.97	100.11	.11	.0	4.6

[1] From other Statesville samples.
[2] Trace.

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In table 19 is given the chemical analysis of the colloid of the Cecil profile. The most notable thing about the table is the constancy of

TABLE 19.—*Chemical analysis of Cecil sandy clay loam (colloid)*

Sample no.	Horizon	Depth	SiO_2	Fe_2O_3	Al_2O_3	MgO	CaO	K_2O	Na_2O	TiO_2	MnO	P_2O_5	Ignition loss	Total	Organic matter	CO_2 from carbonates
		Ins.	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
9415	A	0- 6	30.90	14.57	32.58	0.39	0.60	0.32	0.05	1.13	0.35	0.38	17.85	99.12	4.42	0.0
9416	B_1	6-32	33.88	17.11	32.30	.22	.21	.23	.08	.84	.07	.26	13.91	99.11	.64	.0
9417	B_2	32-60	34.27	17.10	33.03	.13	.21	.26	.08	.83	.08	.27	12.97	99.23	.55	.0
9418	C	60-84	35.13	17.54	30.52	.22	.11	.04	.07	1.65	----	----	12.85	------	.45	.0

composition throughout the profile. The B_1 and B_2 horizons are almost identical in composition, while the A and C show some variation in opposite directions. The slightly greater percentage of silica in the B horizon, as compared with that of the A, is not usual in podzolized soils. It is a real difference even though somewhat accentuated by the rather high percentage of organic matter found in the A horizon. The degree of variation in composition is better brought out by table 20, which shows the various derived data.

TABLE 20.—*Derived data: Cecil sandy clay loam (colloid)*

Sample no.	Horizon	Depth	Molecular ratio								Combined water	Combined water of the soil acid
			$\frac{SiO_2}{Fe_2O_3+Al_2O_3}$	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{Fe_2O_3}$	$\frac{Fe_2O_3}{Al_2O_3}$	$\frac{SiO_2}{\text{Total bases}}$	$\frac{SiO_2}{H_2O}$	$\frac{H_2O}{Al_2O_3}$	$\frac{H_2O}{Fe_2O_3+Al_2O_3}$		
		Ins.									*Pct.*	*Pct.*
9415	A	0- 6	1.25	1.61	5.62	0.286	17.4	0.632	2.55	1.98	13.42	14.60
9416	B_1	6-32	1.33	1.78	5.25	.339	40.1	.743	2.40	1.79	13.26	13.60
9417	B_2	32-60	1.32	1.76	5.31	.331	47.7	.806	2.18	1.64	12.41	12.69
9418	C	60-84	1.43	1.95	5.31	.368	58.8	.830	2.35	1.72	12.39	12.63

The silica-sesquioxide and silica-alumina ratios show that the soil-forming process has brought about a decrease in these ratios. Thus the colloid of the sandy A horizon is more lateritic, even, than the lateritic material from which it is formed. The silica-iron ratio remains fairly constant throughout the profile although evidence of fractionation of the colloid appears in both this and the iron oxide-alumina ratios. The quantity of bases present is so small that a comparison of the silica-total bases ratios of the various horizons is not very reliable. It is noteworthy, however, that the ratio for the C horizon is more than three times that of the A. It has been mentioned that this higher quantity of bases in the A horizon is associated with the presence of organic matter in this layer. The combined water and combined water of the soil acid are rather constant throughout. The 1-percent higher value for combined water of the soil acid found in the A horizon may be due to error in the factor for estimating organic matter. The water-alumina and water-sesquioxide values in the A horizon may be high owing to the same error or to a greater degree of hydration in the A layer.

THE COLUMBIANA CLAY PROFILE

The Columbiana clay profile was selected by H. H. Bennett as a highly aluminous Laterite, occurring in the vicinity of Columbiana in Costa Rica. He describes it as "an extraordinarily friable red clay which is naturally well drained, is strongly resistant to erosion, is easily tilled, and highly productive. The land may be plowed immediately after a heavy rain." It is described by H. Rowe of the United Fruit Co. as derived from volcanic material. The profile, as collected, is described by T. D. Rice of the Division of Soil Survey as follows:

0 to 10 inches, very dark clay. When the material is broken out it falls apart into finely granular particles and occasionally forms rounded clods. The clods are brittle and break up readily under slight pressure, but do not fall apart or melt down when saturated with water.

10 to 25 inches, very dark brown clay with slight reddish tinge. The material breaks up forming aggregates that vary in size from fine granules to rounded clods an inch or more in diameter. The clods are more compact than those of the surface layer.

25 to 40 inches, dark-brown clay with more yellow color than the layers above. This layer is firm in position but breaks up into rounded clods and a small proportion of finely granular material. The clods are more compact and appear to be remnants of decomposed rock.

40 to 92 inches, partly decomposed parent material. The color is dark yellowish brown speckled with various colors of weathered minerals. The material is compact but can be crushed under considerable pressure.

92 to 104 inches, partly decomposed parent material; yellowish brown with white specks. It is not so compact as the layer above and breaks up under pressure into fine granules.

104 to 124 inches, this material in general is light colored with gray, white, and dark-brown streaks and concretions. It breaks up more readily than the layer above and forms a light grayish-yellow powder.

Table 21 shows the mechanical analysis of the Columbiana profile. In this case the mechanical analysis has very little significance, since the soil is made up almost entirely of aggregates. The amount of colloid or clay obtained depends on the quantity of these broken down and the permanence of dispersion obtained. These soils were very difficult to disperse and no adequate degree of dispersion was obtained of sample 9807 either during mechanical analysis or while extracting the colloid.

TABLE 21.—*Mechanical analysis of Columbiana clay*

Sample no.	Horizon	Depth	Fine gravel (2–1 mm)	Coarse sand (1–0.5 mm)	Medium sand (0.5–0.25 mm)	Fine sand (0.25–0.1 mm)	Very fine sand (0.1–0.05 mm)	Silt (0.05–0.005 mm)	Clay (0.005–0 mm)	Colloid (0.002–0 mm)	Organic matter by H_2O_2
		Inches	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
9804	A_1	0– 10	0.4	0.9	2.0	5.1	12.8	28.8	45.2	37.9	4.5
9805	A_2	10– 25	.3	.9	2.2	5.2	7.8	28.6	52.4	52.1	2.3
9806	A_3	25– 40	.3	.7	1.7	6.3	8.3	22.5	58.9	50.8	1.0
9807	B	40– 90	2.3	9.2	8.3	18.9	21.2	29.2	9.8	5.1	.8
9808	C_1	92–104	5.6	8.5	5.3	8.0	8.5	30.1	33.7	22.3	.2
9809	C_2	104–124	2.4	7.0	5.3	9.0	10.0	32.3	33.3	22.1	.5

The results of the chemical analysis of the Columbiana clay are given in table 22. This table also shows the pH determinations on these samples. They are not so acid as the Cecil and Ruston, but more acid than the other soils considered previously. The organic

matter by the hydrogen peroxide method (table 21) is considerably lower than the figures reported by the combustion method (table 22).

TABLE 22.—*Chemical analysis of Columbiana clay (soil)*

Sample no.	Horizon	Depth	SiO_2	Fe_2O_3	Al_2O_3	MgO	CaO	K_2O	Na_2O	TiO_2	MnO	P_2O_5	SO_3	Ignition loss	Total	Organic matter	CO_2 from carbonates	pH
		Inches	*Per-cent*	*Per-cent*	*Per-cent*	*Per-cent*	*Per-cent*	*Per-cent*	*Per-cent*	*Per-cent*	*Per-cent*	*Per-cent*	*Per-cent*	*Per-cent*	*Per-cent*	*Per-cent*	*Per-cent*	
9804	A_1	0- 10	19.80	15.60	37.09	0.50	0.25	0.14	0.23	2.02	0.26	0.31	0.24	24.10	100.54	6.01	0.0	5.1
9805	A_2	10- 25	20.40	16.28	37.76	.43	.10	.14	.22	2.03	.23	.31	.15	22.03	100.08	3.97	.0	5.3
9806	A_3	25- 40	19.66	17.00	38.47	.15	.19	.20	.00	2.44	.26	.28	.22	21.32	100.19	2.41	.0	5.0
9807	B	40- 90	21.08	16.99	38.46	1.80	.29	.10	.00	2.17	.18	.67	.34	18.47	100.55	.59	.0	5.4
9808	C_1	92-104	33.54	17.00	32.82	.49	.28	.00	.00	1.76	.20	.34	.10	13.93	100.46	.14	.0	5.8
9809	C_2	104-124	39.79	6.78	36.90	.23	.18	.04	.00	1.95	.04	.19	.07	14.20	100.37	.11	.0	5.1

The low values are probably due to the catalytic action of manganese dioxide present (*16*). The organic matter in the soil remains relatively high to an unusual depth. It appears when all the characteristics of this soil are considered that the first three samples together form the A horizon. Whether any horizonal difference warrants the other designations is uncertain. The most striking point to be observed is the low percentage of silica throughout the profile. The source material presumably was originally volcanic ash and contained relatively little or perhaps no quartz. The silica present as combined silica has been progressively removed by leaching as the material decomposed. If it be assumed that the geologic material was uniform to the depth of the sample (124 inches) when deposited, then it follows that the silica percentage has been reduced in the first layer to one-half its original value. The iron oxide percentage, on the other hand, has more than doubled on the same basis. The percentage of alumina remains rather constant throughout the profile. The magnesium oxide percentage shows an increase in the fourth layer which is unexplainable on the basis of soil-forming processes. It is likely that the volcanic ash at this depth contained some material high in magnesium which was not present in the other layers, or present to less extent. The same is true of the phosphorus pentoxide content, which is high in this particular layer. There is not enough variation in the percentage of the other constituents to warrant any particular comment.

The results of the chemical analysis of the colloid extracted from the Columbiana clay shown in table 23 reveal a remarkable similarity to those of table 22. An examination of these two tables shows that the corresponding values in the two are very good duplicates of each other in many cases, particularly in the A-horizon samples. This can only mean that the whole soil is or was colloidal in character. The material must have been very fine volcanic ash and originally uniform in composition. The percentages of silica in the colloid of the first 3 layers are practically constant. They increase materially in the lower 3 layers. The iron oxide percentages remain practically constant, save in the last layer which has a much lower value. The colloid from this layer is white, indicating the absence of any ferric oxide. Layer 5, from standpoint of color, is a transition from the deep brown of the first 4 layers to the white of the bottom layer.

The color indicates the presence of the iron as the oxide. The percentage of alumina remains reasonably constant in the first 4 layers of the profile. The magnesium oxide percentage increases in the fourth layer colloid as it did in the soil analysis, but to less degree. The distribution of calcium is rather uniform and is normal throughout the profile. The colloids are, without exception, low in both potash and soda. Phosphorus pentoxide, as was the case in the soil analysis, is highest in the fourth layer. The organic matter concentrates to some extent in the extracted fraction, but not to the degree found in the profiles considered previously in this bulletin. The ignition loss indicates a high percentage of combined water.

TABLE 23.—*Chemical analysis of Columbiana clay (colloid)*

Sample no.	Horizon	Depth	SiO_2	Fe_2O_3	Al_2O_3	MgO	CaO	K_2O	Na_2O	TiO_2	MnO	P_2O_5	Ignition loss	Total	Organic matter	CO_2 from carbonates
		Inches	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
9804	A_1	0– 10	22.04	15.36	36.02	0.23	0.33	0.18	0.07	1.83	0.18	0.48	24.11	100.83	6.44	0.0
9805	A_2	10– 25	22.32	16.15	36.50	.43	.20	.17	.11	1.93	.15	.33	22.51	100.80	4.80	.0
9806	A_3	25– 40	22.01	16.26	37.58	.35	.15	.18	.05	1.81	.14	.36	21.66	100.55	3.81	.0
9807	B	40– 90	26.59	15.48	36.51	.77	.14	.08	.00	2.20	.12	.61	17.67	100.17	1.75	.0
9808	C_1	92–104	32.09	18.56	31.50	.15	.12	.15	.00	1.81	.34	.42	15.04	100.18	1.07	.0
9809	C_2	104–124	39.36	6.95	35.72	.13	.12	.04	.00	2.88	.08	.16	14.57	100.01	.55	.0

The derived data for the colloid of the Columbiana profile are shown in Table 24. The silica-sesquioxide ratio falls below unity in the first

TABLE 24.—*Derived data: Columbiana clay (colloid)*

Sample no.	Horizon	Depth	Molecular ratio $\frac{SiO_2}{Fe_2O_3+Al_2O_3}$	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{Fe_2O_3}$	$\frac{Fe_2O_3}{Al_2O_3}$	$\frac{SiO_2}{\text{Total bases}}$	$\frac{SiO_2}{H_2O}$	$\frac{H_2O}{Al_2O_3}$	$\frac{H_2O}{Fe_2O_3+Al_2O_3}$	Combined water	Combined water of soil acid
		Inches									*Percent*	*Percent*
9804	A_1	0– 10	0.81	1.04	3.78	0.273	21.4	0.366	2.83	2.22	17.67	17.98
9805	A_2	10– 25	.81	1.01	3.66	.283	18.5	.369	2.73	2.19	17.71	18.07
9806	A_3	25– 40	.78	.99	3.59	.277	22.7	.362	2.74	2.15	17.85	18.14
9807	B_1	40– 90	.97	1.24	4.55	.271	18.3	.486	2.54	2.00	15.92	16.35
9808	B_2	92–104	1.25	1.78	4.58	.377	43.6	.675	2.56	1.86	13.98	14.20
9809	C	104–124	1.66	1.87	15.00	.124	96.0	.831	2.25	2.00	14.02	14.14

four layers, while it is 1.25 in the fifth and 1.66 in the sixth. The fact that this ratio for the first horizon is less than one-half that for the deepest layer indicates that the soil-forming process here is one of laterization. In the case of the Cecil we have lateritic soil forming from material which was already lateritic, while in the Columbiana we have a Laterite soil forming from less lateritic parent material. The fact that the material is relatively nonlateritic at the depth of the sixth layer indicates that, comparatively speaking, the soil may be of recent origin. The silica to iron oxide ratio shows clearly the relative increase of iron during the weathering of the material. The silica to alumina ratio remains essentially constant in the first 3 layers, and increases in the 3 deeper layers. This may be significant

as indicating that a quasi-equilibrium ratio between the silica and alumina is reached in the dispersed material. This ratio has a value of 1.04, 1.01, and 0.99 for the first 3 horizons. Prior to the time when this ratio is reached silica is removed in greater molecular quantities than is alumina. After this ratio has been reached, if solution takes place, it is in equimolecular proportions. There is a strong indication that the alumina and silica are combined in the proportion of 1 to 1. If the data given by Anderson and Byers (*2*) on the Nipe clay are recalculated to give the silica-alumina ratios the following are found: 0 to 12 inches, 1.10; 12 to 60 inches, 0.82; 100 to 144 inches, 1.22.

Even though the soil has a silica-sesquioxide ratio of 0.17 to 0.42, the silica-alumina ratio of the colloid does not fall appreciably below unity. The silica to total base ratio is high for two reasons: (1) The soil-forming material contained low percentages of bases, and (2) leaching has been very thorough.

The combined water and combined water of the soil acid are somewhat higher than the corresponding values for the Cecil soils. Again the upper portion of the soil colloid is more highly hydrated than the lower, indicating that the process of hydration proceeds along with the soil-forming processes. There is no evidence of irreversible dehydration of the colloid by wetting and drying, at least with respect to the water classed as combined water. The ratio of water to alumina increases from bottom to top. The same is true of the water-sesquioxide ratio. This progressive increase of water ratios is capable of the same divergent interpretations as those discussed on page 11.

THE PODZOL PROFILES

The soils considered so far in the Pedalfer group have represented progressive weathering of the minerals. The same forces which have brought about changes in the surface horizon have also acted on the lower layers, but to less extent. The accumulation of iron oxide and alumina in the B horizon has been brought about chiefly by mechanical rather than chemical forces. The Podzol soils present a somewhat different situation. The formation of Podzols represents not only mechanical accumulation of the finer materials in the B horizons but also a change in the chemical composition of the colloidal material accumulated. This material enriching the B horizon may consist of iron oxide, alumina, or organic matter. The organic matter may or may not be chemically combined with the sesquioxides.

Briefly, the Podzol profile as developed in the United States may be described as follows: Underneath the surface litter is a layer of well-decomposed organic matter mixed with rather sandy mineral matter. It is dark in color, owing to the presence of the organic matter. Underneath this layer is a gray one containing relatively little colloid and organic matter. It is very thoroughly leached. Beneath this layer is the B horizon, or zone of enrichment. It is a dark-brown layer rich in the oxides of iron, alumina, and organic matter, as already mentioned. The color is more intense at the upper portion of the layer and grades off as it ranges downward to the parent material. The C horizon may be a variety of materials but is lower in the oxides of iron and alumina than the B horizon.

Two Podzols are considered in this bulletin, the Caribou loam from Maine and the Au Train sand from Michigan.

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THE CARIBOU LOAM PROFILE

The Caribou is the predominating soil series of the "big woods" area of the New England States and of a portion of Canada. This is the famous "potato" soil of Maine. The Caribou loam has developed on well-drained areas of heavy vegetative cover.

The soil profile used in this investigation was collected in a virgin spruce forest 5 miles northeast of Presque Isle, Maine. The soil profile is described as follows:

Horizon A_1, 0 to ¾ inch. Composed of black pellets which seem to be the casts of earthworms which were numerous.

Horizon A_2, ¾ to 2 inches. A gray layer varying from a mere film to 2 inches in thickness.

Horizon B_1, 2 to 4 inches. Rich brown, very variable in thickness, slightly heavier and more compact than A_2.

Horizon B_2, 4 to 6 inches. A bright yellow brown and heavier than the B_1.

Horizon C, 8 to 24 inches. A greenish blue-gray color and composed of unweathered glacial drift. Caribou parent material is glacial till derived from shaly limestone.

The mechanical analysis of the Caribou profile is shown in table 25. The most notable feature of the table is the indication that mechanical fragmentation is taking place, the first four grades of sand sizes being much more abundant in the C horizon than in the upper layers. This fragmentation may be caused both by mechanical and by chemical processes. The B_1 and B_2 horizons are, as in the podzolic soils already considered, heavier in texture than either the A or the C. The organic matter as indicated by the peroxide method is very high in the A_1 layer and drops sharply in the gray layer. The accumulation of organic matter in the B horizon is not marked in the soil as a whole.

TABLE 25.—*Mechanical analysis of Caribou loam* [1]

Sample no.	Horizon	Depth	Fine gravel (2–1 mm)	Coarse sand (1–0.5 mm)	Medium sand (0.5–0.25 mm)	Fine sand (0.25–0.1 mm)	Very fine sand (0.1–0.05 mm)	Silt (0.05–0.005 mm)	Clay (0.005–0 mm)	Colloid (0.002–0 mm)	Organic matter by H_2O_2
		Inches	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
10540	A_1	0–¾	1.1	1.9	1.8	3.8	7.3	35.6	23.0	13.8	23.4
10541	A_2	¾– 2	1.4	2.1	2.0	4.1	10.5	51.4	23.1	12.3	4.8
10542	B_1	2– 4	2.7	3.1	2.4	4.3	9.4	42.5	29.9	18.3	4.9
10543	B_2	4– 6	3.5	4.3	2.6	4.2	9.2	42.8	29.2	15.6	3.4
10544	C	8–24	10.8	12.0	7.4	11.8	10.9	28.4	18.0	10.7	.3

[1] Determinations by H. W. Lakin and T. M. Shaw.

Table 26 shows the chemical analysis of the Caribou profile. The silica percentage is relatively low in the A_1 owing to the diluting effect of the organic matter. In the gray layer the silica content runs very high and then shades off in the B_1 and B_2 due to the presence of the oxides of iron and alumina. The parent material, C, is higher in silica than the B horizon. The percentages of iron and alumina rise in a characteristic manner in the B_1 and B_2 and drop slightly in the C. There is nothing in the percentages of bases requiring comment. The ignition loss in this case is practically all organic matter. The pH determinations indicate a very acid condition throughout the profile, which is characteristic of all soils found under coniferous forests.

TABLE 26.—*Chemical analysis of Caribou loam (soil)* [1]

Sample no.	Horizon	Depth	SiO_2	Fe_2O_3	Al_2O_3	MgO	CaO	K_2O	Na_2O	TiO_2	MnO	P_2O_5	SO_3	Ignition loss	Total	Organic matter	N	pH
		Inches	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	
10540	A_1	0–¾	57.49	2.47	7.83	0.63	1.25	0.87	0.99	0.75	0.20	0.21	0.29	27.18	100.16	25.26	0.86	5.1
10541	A_2	¾– 2	78.95	2.07	8.29	.45	.38	1.06	1.31	1.06	.08	.10	.20	6.25	100.20	3.86	.22	4.2
10542	B_1	2– 4	69.22	5.28	11.59	1.08	.50	1.21	1.36	.92	.09	.23	.13	8.54	100.15	5.52	.23	4.5
10543	B_2	4– 6	64.63	6.67	14.32	1.66	.41	1.30	1.36	.93	.06	.16	.16	8.40	100.06	4.17	.12	4.7
10544	C	8–24	70.89	5.27	13.39	1.80	.48	1.49	1.79	.85	.05	.11	.17	3.42	99.71	.86	.08	5.6

[1] Determinations by G. Edgington.

The results of the chemical analysis of the colloids extracted from the Caribou profile are shown in table 27. The percentages of silica are lower in the B_1 and B_2 than in the other horizons. This reflects the increase in iron oxide and alumina content, shown in the next two columns. In this particular Podzol it is seen that there has been enrichment only with respect to the iron oxide. There has been no marked accumulation of either alumina or organic matter relative to the soil as a whole. The distribution of bases throughout the profile is normal. The high percentages of magnesium and potassium indicate considerable unweathered minerals throughout the profile. The organic matter is very high, in comparison with the soils already studied, down to the C horizon.

TABLE 27.—*Chemical analysis of Caribou loam (colloid)*

Sample no.	Horizon	Depth	SiO_2	Fe_2O_3	Al_2O_3	MgO	CaO	K_2O	Na_2O	TiO_2	MnO	P_2O_5	SO_3	Ignition loss	Total	Organic matter	N
		Inches	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
10540	A_1	0–¾	34.57	5.26	16.90	1.18	1.27	2.57	0.21	1.15	0.18	0.38	0.50	36.67	100.84	29.27	1.70
10541	A_2	¾– 2	43.31	4.82	21.84	1.33	.72	2.62	.16	1.25	.12	.57	.26	23.18	100.18	13.52	1.20
10542	B_1	2– 4	32.06	15.68	19.67	1.47	.67	2.07	.06	.81	.08	.65	.27	27.43	100.92	16.90	.94
10543	B_2	4– 6	28.09	17.62	22.16	1.77	.26	1.03	.33	.69	.05	.42	.34	27.44	100.20	14.55	.63
10544	C	8–24	38.29	13.08	25.40	2.80	.26	3.85	.09	.97	.18	.32	.11	14.64	99.99	5.43	.66

The derived data for the Caribou are given in table 28. The decreases in silica-sesquioxide ratio in the B_1 and B_2 horizons indicate

TABLE 28.—*Derived data: Caribou loam (colloid)*

Sample no.	Horizon	Depth	Molecular ratio							Combined water	Combined water of soil acid
			$\frac{SiO_2}{Fe_2O_3+Al_2O_3}$	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{Fe_2O_3}$	$\frac{Fe_2O_3}{Al_2O_3}$	$\frac{SiO_2}{\text{Total bases}}$	$\frac{SiO_2}{H_2O}$	$\frac{H_2O}{Al_2O_3}$	$\frac{H_2O}{Fe_2O_3+Al_2O_3}$	
		Inches								*Pct.*	*Pct.*
10540	A_1	0–¾	2.89	3.47	17.5	0.198	6.76	1.40	2.48	2.03	7.40	12.63
10541	A_2	¾– 2	2.95	3.36	23.9	.141	9.25	1.34	2.50	2.19	9.66	12.80
10542	B_1	2– 4	1.83	2.76	5.43	.509	7.36	.811	3.41	2.26	10.53	14.25
10543	B_2	4– 6	1.43	2.15	4.24	.507	7.15	.598	3.59	2.38	12.89	16.46
10544	C	8–24	1.92	2.56	7.78	.329	5.35	1.01	2.53	1.90	9.21	12.00

the characteristic podzolization process. An examination of the silica-iron oxide and silica-alumina ratios indicates that there has been an accumulation of both these constituents in the B layers. The silica-sesquioxide ratio in the B_2 approaches that of the lateritic soils, while that of the A horizons corresponds to the Gray-Brown Podzolic group. The silica to total bases ratio shows a rather young soil colloid, since it is not leached to the extent of the Red and Yellow soils of the coastal plains, although it has a heavier rainfall. The profile development, however, is good. The calculation of combined water of the soil acid is limited in value in the case of this and other Podzol soil colloids, because the organic matter subtracted from the ignition loss involves the use of the organic factor which is very uncertain. The correction factor, therefore, renders the combined water values used to obtain the combined water of the soil acid quite inaccurate. Also, in this soil, the bases associated with the organic matter and the probable presence of unweathered colloid minerals make any conclusions based upon the water relations at best of only qualitative significance (p. 4).

THE AU TRAIN SAND PROFILE

The Au Train sand is also a Podzol, but differs from the Caribou in that it is derived from almost pure sand. The sample was collected in Luce County, Mich. The horizons are described as follows:

Horizon A_1, 0 to 2 inches. Leaf litter and mold.
Horizon A_2, 2 to 10 inches. Gray sand.
Horizon B_1, 10 to 12 inches. Very dark brown loamy sand.
Horizon B_2, 12 to 40 inches. Yellowish- or reddish-brown sand.
Horizon C, 40 to 60 inches. Pale-yellow sand.

The mechanical analysis of this profile is shown in table 29. With the exception of the organic matter in the A_1 horizon, this soil is almost all medium and fine sand. The quantities of colloid are so small that it is evident the collection of colloid and of significant analytical data presents a difficult problem. Since Podzols of like character are of extensive occurrence, the data presented have value, even though quantitative inferences are perhaps unwarranted.

TABLE 29.—*Mechanical analysis of Au Train sand* [1]

Sample no.	Horizon	Depth	Fine gravel (2–1 mm)	Coarse sand (1–0.5 mm)	Medium sand (0.5–0.25 mm)	Fine sand (0.25–0.1 mm)	Very fine sand (0.1–0.05 mm)	Silt (0.05–0.005 mm)	Clay (0.005–0 mm)	Colloid (0.002–0 mm)	Organic matter by H_2O_2
		Inches	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
10644	A_1	0– 2	0.1	2.8	14.4	22.2	2.6	5.7	5.7	4.6	44.7
10645	A_2	2–10	.8	13.2	40.3	36.4	3.7	3.5	1.4	.7	.3
10646	B_1	10–12	.8	9.4	30.2	46.2	5.5	1.4	2.3	.8	2.6
10647	B_2	12–40	.5	5.8	23.2	60.9	6.0	.8	1.1	1.3	1.2
10648	C	40–60	.0	3.2	32.2	60.2	3.6	.1	.5	.4	.0

[1] Determinations by H. W. Lakin and T. M. Shaw.

The chemical analysis of the Au Train profile is shown in table 30. The silica content represents almost all the sample in every case

except the A_1 which has 42.49 percent ignition loss.[3] As was the case with the Caribou the percentage of alumina is highest in the B_1 and B_2 horizons. The iron percentages are so small that they mean but little. Both calcium and potassium are present to a surprising extent, which fact probably accounts for the vegetation being able to form the soil. Organic matter has accumulated in the B layers in excess of that in the A_2.

TABLE 30.—*Chemical analysis of Au Train sand (soil)* [1]

Sample no.	Horizon	Depth	SiO_2	Fe_2O_3	Al_2O_3	MgO	CaO	K_2O	Na_2O	TiO_2	MnO	P_2O_5	SO_3	Ignition loss	Total	Organic matter	N	pH
		Ins.	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	
10644	A_1	0- 2	51.84	0.47	2.39	0.07	0.86	0.86	0.13	0.14	0.24	0.12	0.28	42.49	99.89	----	1.13	5.8
10645	A_2	2-10	95.49	.16	2.12	(2)	.15	.98	.18	.09	.01	.01	.01	.68	99.88	0.63	.02	4.3
10646	B_1	10-12	87.40	.79	4.92	.01	.26	1.96	.24	.17	.02	.06	(2)	3.70	99.53	2.11	.07	4.6
10647	B_2	12-40	90.84	.50	4.29	(2)	.26	1.73	.31	.11	.01	.03	(2)	1.41	99.49	1.02	.02	5.2
10648	C	40-60	92.99	.50	3.76	.02	.24	1.66	.36	.12	.01	.02	(2)	.24	99.92	.10	.01	5.9

[1] Determinations by G. Edgington.
[2] Trace.

The results of the chemical analyses of the colloids from the Au Train sand are given in table 31. As is evident from the texture of the soil

TABLE 31.—*Chemical analysis of Au Train sand (colloid)*

Sample no.	Horizon	Depth	SiO_2	Fe_2O_3	Al_2O_3	MgO	CaO	K_2O	Na_2O	TiO_2	MnO	P_2O_5	SO_3	Ignition loss	Total	Organic matter	N
		Ins.	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
10644		(1)	0- 2	1.00	0.25	1.08	0.53	2.73	0.83	0.89	(2)	1.00	0.54	----	90.64	[3]99.49	72.03	5.68
10644	A_1	0- 2	12.35	.98	3.81	.45	1.60	.32	.40	0.11	.43	.37	----	79.56	100.38	74.16	2.66
10645	A_2	2-10	47.27	3.51	14.19	.57	.48	.62	.56	(2)	.07	.37	----	31.75	99.39	25.53	1.40
10646	B_1	10-12	11.86	6.53	16.88	.33	.54	.62	.22	(2)	.09	.39	----	62.58	100.04	48.45	1.01
10647	B_2	12-40	12.38	4.70	23.95	.25	.41	.48	.36	.26	.09	.39	----	57.47	100.74	40.46	.87
10648	C	40-60	(4)	----	----	----	----	----	----	----	----	----	----	----	----	----	----

[1] The water-soluble extract of the soil.
[2] Quantities not determined.
[3] Total is low due to K and Na being estimated as oxides when they are largely carbonates.
[4] No colloid in quantity sufficient for examination could be obtained.

(table 29), the extraction of the colloids in sufficient quantities was difficult because of the small amount present and it would seem to follow that if colloidal silica exists in the soil its presence would be exceptionally marked in these colloids. It was impossible to get even muddy water from the C horizon of the soil, hence no analysis for the colloid could be made. Included in the table is the analysis of the residue obtained by evaporation of the highly colored filtered extract from the A horizon. It has a certain interest as representing the character of the soluble material obtained from this soil. The data of table 31 show the accumulation of iron oxide, alumina, and organic matter in the B_1 and B_2 horizons which is characteristic of Podzol colloids. The organic carbon of these colloids is very high in all four of the colloids. Indeed, it is almost proper to consider them as organic colloids contaminated by mineral colloids.

[3] No organic-matter determination was made of the A_1 horizon, because the sample was lost before the analyses of organic carbon were started.

The derived data for the Au Train colloids are given in table 32. The high silica-sesquioxide and silica-alumina ratios of the A_1 and A_2

TABLE 32.—*Derived data: Au Train sand (colloid)*

Sample no.	Horizon	Depth	Molecular ratio								Combined water	Combined water of soil acid
			$\frac{SiO_2}{Fe_2O_3+Al_2O_3}$	$\frac{SiO_2}{Al_2O_3}$	$\frac{SiO_2}{Fe_2O_3}$	$\frac{Fe_2O_3}{Al_2O_3}$	$\frac{SiO_2}{\text{Total bases}}$	$\frac{SiO_2}{H_2O}$	$\frac{H_2O}{Al_2O_3}$	$\frac{H_2O}{Fe_2O_3+Al_2O_3}$		
		Inches									*Per-cent*	*Per-cent*
10644	A_1	0- 2	4.72	5.49	33.7	0.163	3.70	0.578	9.51	8.17	5.40	24.81
10645	A_2	2-10	4.88	5.65	35.8	.158	20.0	2.04	2.76	2.39	6.22	9.30
10646	B_1	10-12	.95	1.19	4.82	.247	6.76	.242	4.91	3.95	14.13	28.47
10647	B_2	12-40	.78	.88	7.01	.125	8.02	.212	4.13	3.67	17.01	29.36

horizons are probably to be regarded as due to the presence of quartz particles of colloidal dimensions or of silica gel rather than as due to combined silica in an alumino-silica complex. The silica ratios all decrease in the B horizon in the manner characteristic of Podzols. In the presence of such large quantities of organic matter the water ratios are even less reliable in this profile than in the Caribou profile.

GENERAL DISCUSSION

The profile data presented in detail in tables 1 to 32, inclusive, are derived from a group of soils selected for the primary purpose of obtaining the distinguishing analytical characteristics associated with the field differentiation of the great soil groups. For the purpose of bringing the differences into clear relief the more instructive of the derived data are assembled into separate tables. For simplicity the portions of each horizon (or other subdivision) are averaged in tables 33 to 38. The data are arranged in the order of the previous treatment.

SILICA-SESQUIOXIDE RATIOS

The most widely used, and in some respects the most generally useful, ratio found in the tables of derived data is that of silica to sesquioxides. It was found by Holmes (*9*) and by Holmes and Edgington (*10*) that this ratio has a characteristic value for the colloid of a given soil series. Table 33 gives the silica-sesquioxide ratios for

TABLE 33.—*Silica-sesquioxide ratios for colloids of 8 soils*

Horizon	Ratios for soil series indicated							
	Barnes	Carrington	Miami	Ruston	Cecil	Columbiana	Caribou	Au Train
A	3.05	2.46	2.86	1.60	1.25	0.80	2.93	4.80
B	3.13	2.34	2.60	1.53	1.33	1.11	1.63	.87
C	3.36	2.36	2.63	1.57	1.43	1.66	1.92	----------

the soil colloids of the 8 soils considered in this investigation. For the first 5 of these no sharp differences appear, which would indicate no great difference in the colloids of the three horizons. In the Barnes colloid the lowest ratio appears in the upper portion of the profile. In the Carrington, Miami, and Ruston the highest ratio is in the upper portion. In the Cecil soil only a very moderate increase with depth is noted. The divergence in the profile is more marked in the last 3 soils. In the Columbiana soil the removal of silica from the A horizon is shown to be extensive. The 2 Podzols show the special characteristic of the Podzol colloids; high silica in the A horizon and marked decrease in the B.

The degree of uniformity of colloid composition in all the profiles, as shown by the silica-sesquioxide ratio, is taken to indicate that the colloid accumulation in the B horizon is effected chiefly by transfer downward of the whole colloid. In the Podzols definite fractionation is indicated, probably induced by the type of organic matter derived from coniferous vegetation usually found on these soils. The Miami soil, representative of the Gray-Brown Podzolic group, shows definite indication of similar behavior to a less marked degree.

A progressive lowering of the silica-sesquioxide ratio is observed in the first 6 colloids, with the exception of the Miami. It has been observed (p. 11) that the potassium content of this colloid indicates the probable presence of unweathered feldspars. If it be assumed that all the potassium is present as unweathered orthoclase, and the silica-sesquioxide ratios be calculated upon this assumption, the values obtained become 2.41, 2.22, and 2.01 for the A, B, and C horizons. This sweeping assumption is not warranted but it serves to indicate that the gross composition of the colloid may not be an accurate indication of the composition of the dominant colloid complex. McCaughey and Fry (*11*) found much feldspathic material in the sands and silts of the soils developed from glacial drift. It does not necessarily follow that such material is present in the colloid, but it seems extremely probable that it is.

SILICA-ALUMINA RATIOS

The silica-alumina ratios for the colloids are given in table 34. They show in general the same kind of variation from Chernozem to Laterite, as is shown in table 33 by the silica-sesquioxide ratios. In the Barnes and Carrington soils, part, if not all, of the iron present is assumed to be a portion of the characteristic colloid complex. These colloids are nearly white after treatment with hydrogen peroxide. Hence, for these soils, the ratios of table 33 are more indicative of the colloid complex than those of table 34. In the case of the Miami by no means all of the iron is a part of the silicate complex, but apparently a portion of it is. In the A and B horizons of the remaining soils, including the Podzols, the iron is probably present as the free oxide, or hydroxide, hence the silica-alumina ratio better characterizes the composition of these soil acid complexes. In the C horizon of the Columbiana, which is very light colored, it appears that the iron is probably partly combined with the silica. It is interesting to note that in the Columbiana the silica-alumina ratio does not go below 1. In the little-weathered Barnes, it is upward of 4, but the colloid acid complex, since it contains iron, is not properly

so expressed. It would seem proper to assume that this complex is best represented by a value lying in the neighborhood of 3.5. The extremely high silica-alumina ratio of the Au Train A horizon is probably due to the presence of free silica of collodial dimensions. The mechanical analysis of this soil shows its extremely sandy character.

TABLE 34.—*Silica-alumina ratios for colloids of 8 soils*

Horizon	Ratios for soil series indicated							
	Barnes	Carrington	Miami	Ruston	Cecil	Columbiana	Caribou	Au Train
A	4.07	3.20	3.48	2.01	1.61	1.01	3.42	5.57
B	4.16	3.10	3.41	1.90	1.77	1.48	2.46	1.03
C	4.41	3.23	3.41	1.93	1.95	1.87	2.56	----------

SILICA-TOTAL BASE RATIOS

In table 35 are assembled the ratios by formula weights of the silica to total bases. The most striking feature of the relations between the soil groups illustrated by this table is the wide contrast between the total base content of the Laterite and lateritic soils as compared with the five other soils. The extremely low base content of the Ruston, Cecil, and Columbiana soils indicated by this ratio is further accentuated by the low content of silica. In this relation, as in the others, the failure of the Miami to correspond to what would appear to be its proper position in the series may with fair reason be ascribed to its unweathered mineral content. The relations shown by the Carrington, Miami, Caribou, and Au Train all indicate a higher base content and less weathering in the C horizon than in the A, with no similar uniformity showing itself with respect to the B. The relatively small variation in the Chernozem, the Barnes, is to be expected, by reason of the low rainfall under which it develops.

TABLE 35.—*Silica-total base ratios for the colloids of 8 soils*

Horizon	Ratios for soil series indicated							
	Barnes	Carrington	Miami	Ruston	Cecil	Columbiana	Caribou	Au Train
A	6.96	8.63	7.65	21.8	17.4	21.3	8.01	11.85
B	7.12	9.28	6.49	21.7	43.4	43.6	7.21	6.76
C	7.27	8.02	6.79	21.7	58.8	96	5.35	8.02

The very marked decrease in bases at greater depth in the Columbiana and Cecil may properly be ascribed to the retention of bases in the surface soils by organic matter and to the porous character of the substrata which permit ready percolation. Apparently, a different situation in the Ruston is owing in part at least to a more uniform distribution of organic matter.

The high base content of the high silica-sesquioxide soils is undoubtedly due in part to the immaturity of the soils, whether as a result of lack of hydrolysis or of leaching. Nevertheless, this fact may also be attributed in part to the more strongly acid character of the silica-

alumina complexes, which is shown by their base-exchange capacities, pH values after electrodialysis (*2*), and low retention of phosphate ions (*8*).

COMBINED WATER OF THE SOIL ACIDS

In table 36 are assembled the comparative data for the colloids of the combined water of the soil acids (p. 3). While the determined values are subject to unavoidable errors (p. 4) in individual determinations, this comparative value is definite except in the case of the Caribou profile (p. 25). It will be observed that in general the quantities are found to increase as the silica-sesquioxide ratios decrease. The Miami colloid is not in its proper sequence, which is as should be expected from the previous relations discussed. Any trisilicate feldspar present would lower the water content found. The decrease in water content in the C horizon as compared with the solum proper is as should be expected. Attention is also again directed to the probability that the iron oxide content of the Barnes and Carrington colloids is, for the most part, associated with the silica complex, while in the Ruston, Cecil, and Columbiana it is probably both free and nearly, if not quite, dehydrated. In the Podzols it would seem preferable to assume that for the most part the iron oxide is almost, if not completely, hydrated, though adequate evidence for this assumption is not at hand.

TABLE 36.—*Combined water of the soil acids for the colloids of 8 soils*

Horizon	Combined water for soil series indicated							
	Barnes	Carrington	Miami	Ruston	Cecil	Columbiana	Caribou	Au Train
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
A	11.34	12.83	10.56	13.46	14.60	18.06	12.71	17.09
B	10.56	11.79	10.11	13.67	13.15	15.28	15.36	28.91
C	9.99	11.74	8.46	12.79	12.63	14.14	12.00	----------

A more significant relation is brought out if the water-silica and water-alumina relations are compared, as is done in tables 37 and 38. In table 37 the water-silica relations are the reciprocals of the values given in the separate tables of derived data. It will be observed that the ratios in table 37 vary from considerably less than unity, in the Barnes profile, to a maximum of 2.73 in the A horizon of the Columbiana. The organic content and free silica of the Podzol colloids make the relationships shown for the Caribou and Au Train of doubtful significance in this connection. Again, the sequence is disturbed by the presumed presence of unweathered material in the Miami colloid. In table 38 a still more significant relationship is brought out by comparing the formula-weight ratios of water and alumina in the colloids. In the discussion of the constitution of the colloids (p. 31) attention will be called to the possible existence of certain soil acids. In this series of assumptions all colloid acids should have a maximum water-alumina ratio of 3 except when the iron present is wholly, or in part, a portion of the hypothetical alumino-silica complex. In the instances shown in table 38 only in the cases of the A horizon of the Barnes and Carrington and the B horizon of the Caribou is this limit

exceeded (the Au Train profile again not considered for reasons given p. 25). In the Barnes and Carrington, it is clear that the iron is combined as indicated by the color of the complex, and in the Caribou it seems probable that the iron content is, for the most part, hydrated ferric oxide. Even if these variations be not taken into account, the mean water-alumina ratios shown by the first seven soils are for the A horizons, 2.81; for the B, 2.69; and for the C, 2.43.

TABLE 37.—*Water-silica ratios in colloids of 8 soils*

Horizon	Ratios for soil series indicated							
	Barnes	Carrington	Miami	Ruston	Cecil	Columbiana	Caribou	Au Train
A	0.83	1.04	0.70	1.16	1.58	2.73	0.72	2.93
B	.73	.88	.70	1.22	1.29	1.72	1.42	4.42
C	.67	.87	.60	1.10	1.21	1.20	.99	----------

TABLE 38.—*Water-alumina ratios for colloids of 8 soils*

Horizon	Ratios for soil series indicated							
	Barnes	Carrington	Miami	Ruston	Cecil	Columbiana	Caribou	Au Train
A	3.36	3.31	2.43	2.32	2.55	2.77	2.49	6.13
B	3.03	2.74	2.41	2.32	2.29	2.55	3.50	4.52
C	2.94	2.80	2.05	2.11	2.35	2.25	2.53	----------

CONSTITUTION OF THE COLLOIDS

The development and the characteristics of the colloids of a soil profile may be considered as the result of two types of processes. One type consists of those processes which produce fine material from the parent minerals, the other of the processes which involve additions to and subtractions from this material and effect changes in composition and distribution. The profile development proper is largely a consequence of the operation of the second type of process. It is obvious that both types of process operate simultaneously, under normal conditions, and it is impossible to consider them or their effects wholly independently.

The production of the fine material, so far as the inorganic colloid is concerned, may without serious error be considered a result of two primary operations—mechanical weathering and hydrolysis. Mechanical weathering appears to be chiefly responsible for the production of the disintegrated rock which, directly or indirectly, is the material of the soil. This mechanical disintegration may not be considered to have a minimum limit and therefore if it were to operate alone should produce material of colloidal fineness. Recently one of the writers (*6*) presented a series of postulates based on the assumption that the chief colloid-forming process consists in the hydrolysis of crystalline rocks, or of their secondary products. It was assumed that the extent of the hydrolytic process and its rate varied with en-

vironmental conditions. It was further assumed that as this process continued the resultant products should reach a state of pseudo-equilibrium under given conditions and that these products characterized the soil colloids.

According to the hypotheses, the products constituting the fundamental inorganic colloid complexes are definite amphoteric aluminosilicic "acids" with the properties to be expected of such compounds. The colloids themselves are assumed to be salts of these acids, with more or less replacement of acid hydrogen by metals and of hydroxyl groups by acid ions. The iron content of the soils is assumed to play the same role as alumina except that its compounds more readily reach complete hydrolytic decomposition. The possible existence of the following compounds was assumed:

$3H_2O.Al_2O_3.6SiO_2$ montmorillonitic acid.
$3H_2O.Al_2O_3.4SiO_2$ pyrophyllic acid.
$3H_2O.Al_2O_3.2SiO_2$ halloysitic acid.
$3H_2O.Al_2O_3$ aluminium hydroxide.

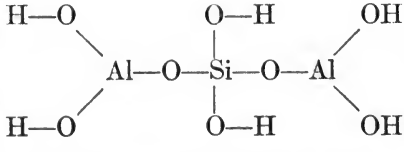
It must, however, be emphasized that no inorganic colloid could reasonably be expected to consist wholly of the derivatives of any one of these acids. It is perhaps reasonable to assume that a given soil colloid may be dominated by one of them. The dominant colloid, however, is marked by the presence of parent material of colloidal dimension, by unremoved decomposition products and variations resulting from the second type of soil profile forming processes referred to above.

A number of facts bearing on the validity of the above assumptions are presented by the study of the soils under consideration.

First and perhaps most important is the fact that the Columbiana soil furnishes in the A horizon a colloid in which the ratio of water to alumina and silica is 2.77 $H_2O.Al_2O_3$: 1.01 SiO_2. This is the only aluminous Laterite available for examination. A ferruginous Laterite, Nipe clay, examined by Anderson and Byers (*2*) gave a colloid having the composition 3.53 $H_2O.Al_2O_3$.1.08 SiO_2, without correction of the ignition loss for organic matter present.

Martin and Doyne (*13*) have made a study of the clay fractions obtained from the Laterite and lateritic soils of Sierre Leone. While they found the whole soil and its coarser fractions to have silica-alumina ratios of less than 1, they were not able to obtain dispersed material with a ratio lower than 1.

In view of these facts the writers make the tentative suggestion that there may exist a laterite colloid "acid", the composition of which may be expressed by the formula



If it exists it may be expected only in soils subjected to intense hydrolytic conditions (high temperature and high rainfall), since clay of the halloysitic type is very stable. A careful examination of soils of the Laterite great group is very desirable since if the compound

exists its isolation in fairly pure condition may be possible. For this hypothetical amphoteric compound the name allophanic acid is suggested. Allophane is a clay mineral of very similar composition.

The first three layers of the Columbiana clay are essentially alike (tables 22 and 23). If it is assumed that all the combined water of the soil acid is associated with the alumino-silicate complex, the following percentages are found: 0 to 10 inches, 23.7; 10 to 25 inches, 23.5; 25 to 40 inches, 23.3. The percentage of water in the fully hydrated hypothetical compound is 25.

A second point of importance demonstrated by the examination of this group of colloids is that no satisfactory evidence of the existence of a colloid containing the complex $3H_2O.Al_2O_2.6SiO_2$ is presented. This is not surprising since "immature" colloids from trisilicates are probably of rare development. It may be also that hydrolytic processes sufficiently intense to hydrolyze albite and orthoclase at rates greater than correspond to erosional effects are sufficiently intense to carry the reaction further and remove the silica freed. The fact that the colloid of the A horizon sometimes exceeds four is not believed to indicate the montmorillonitic type of colloid but rather the existence of free silica.

The expression of the chemical composition of the acid complex of the colloids is recapitulated in table 39. In this table the water and silica content are compared with alumina taken as unity. In making this comparison the assumption, possibly gratuitous, is that in all but the first three colloids all the iron is present as free oxide or hydroxide. In the first three the relations are also expressed on the assumption that the iron is all combined in the ferro-silicate complex. The truth probably lies between these extremes.

The Barnes colloid presents the nearest approach to a composition corresponding to the hypothetical pyrophyllic acid. Were the assumption warranted that the alumino-silicate is the only complex present, then the indication would be faulty in showing excess water of constitution in both the A and B sections of the soil, and the excess silica might be either free silica or due to a complex of a higher silica-alumina ratio. Were the assumption warranted that all iron is combined in the complex, then the ratio is intermediate between the halloysitic and pyrophyllic ratios and might be due either to a mixture of colloids or a dominant colloid acid with the silica-sesquioxide ratio of 3. It is of course improper to make dogmatic assertion in the matter. It may be noted however, that the colloids of the Chernozem, or closely related types reported by Anderson and Byers (*2*) and Brown, Rice, and Byers (*5*) give for the A fractions of the Chernozems a mean value of the ratios: Al_2O_3. 4.31 SiO_2. 3.32 H_2O and M_2O_3. 3.39 SiO_2. 2.66 H_2O.

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TABLE 39.—*Molecular composition of the acid complex of the soil colloid for 3 horizons of 8 soils*

Soil	Horizon A		Horizon B		Horizon C	
	Calculated with Al_2O_3 equal to 1.0	Calculated with sesquioxides (M_2O_3) equal to 1.0	Calculated with Al_2O_3 equal to 1.0	Calculated with sesquioxides (M_2O_3) equal to 1.0	Calculated with Al_2O_3 equal to 1.0	Calculated with sesquioxides (M_2O_3) equal to 1.0
Barnes	1.0 Al_2O_3 4.1 SiO_2 3.4 H_2O	1.0 M_2O_3 3.1 SiO_2 2.5 H_2O	1.0 Al_2O_3 4.2 SiO_2 3.0 H_2O	1.0 M_2O_3 3.1 SiO_2 2.3 H_2O	1.0 Al_2O_3 4.4 SiO_2 2.9 H_2O	1.0 M_2O_3. 3.4 SiO_2. 2.2 H_2O.
Carrington	1.0 Al_2O_3 3.2 SiO_2 3.3 H_2O	1.0 M_2O_3 2.5 SiO_2 2.6 H_2O	1.0 Al_2O_3 3.2 SiO_2 2.7 H_2O	1.0 M_2O_3 2.3 SiO_2 2.1 H_2O	1.0 Al_2O_3 3.2 SiO_2 2.8 H_2O	1.0 M_2O_3. 2.4 SiO_2. 2.0 H_2O.
Miami	1.0 Al_2O_3 3.5 SiO_2 2.4 H_2O	1.0 M_2O_3 2.9 SiO_2 2.0 H_2O	1.0 Al_2O_3 3.4 SiO_2 2.4 H_2O	1.0 M_2O_3 2.6 SiO_2 1.8 H_2O	1.0 Al_2O_3 3.4 SiO_2 2.1 H_2O	1.0 M_2O_3. 2.6 SiO_2. 1.6 H_2O.
Ruston	1.0 Al_2O_3 2.0 SiO_2 2.3 H_2O		1.0 Al_2O_3 1.9 SiO_2 2.3 H_2O		1.0 Al_2O_3 1.9 SiO_2 2.1 H_2O	
Cecil	1.0 Al_2O_3 1.6 SiO_2 2.6 H_2O		1.0 Al_2O_3 1.8 SiO_2 2.3 H_2O		1.0 Al_2O_3 2.0 SiO_2 2.4 H_2O	
Columbiana	1.0 Al_2O_3 1.0 SiO_2 2.8 H_2O		1.0 Al_2O_3 1.5 SiO_2 2.6 H_2O		1.0 Al_2O_3 1.9 SiO_2 2.3 H_2O	
Caribou	1.0 Al_2O_3 3.4 SiO_2 2.5 H_2O		1.0 Al_2O_3 2.5 SiO_2 3.5 H_2O		1.0 Al_2O_3 2.6 SiO_2 2.5 H_2O	
Au Train	1.0 Al_2O_3 5.6 SiO_2 6.1 H_2O		1.0 Al_2O_3 1.0 SiO_2 4.5 H_2O			

The Carrington colloid shows a marked decrease in the silica, as compared with the Barnes colloid, whether compared with alumina or with the sesquioxides. There is relatively less alteration in the water ratios. That the ratios expressed in table 39, for the Carrington, are characteristic for Prairie soils is to be seen by comparison with the mean ratios for the surface portion of the Prairie soils reported by Middleton, Slater, and Byers (*14*), and by Brown, Rice, and Byers (*5*). These are Al_2O_3. 3.39 SiO_2. 2.87 H_2O and M_2O_3. 2.68 SiO_2. 2.28 H_2O. It is to be noted that in the Prairie soils it is to be expected that a portion, but by no means all, of the iron is in the free condition, i. e., as iron oxide.

In the Miami colloid the frequently mentioned presence of unweathered material must be considered. If the same drastic assumption is made as was the case in recalculating the silica-sesquioxide ratios (p. 28) the composition becomes

A. Al_2O_3. 3.06 SiO_2. 2.67 H_2O
B. Al_2O_3. 2.76 SiO_2. 2.76 H_2O
C. Al_2O_3. 2.76 SiO_2. 2.31 H_2O

Undoubtedly this assumption goes beyond the truth in that some of the potassium is associated with the colloid acid and a portion, though perhaps the smaller portion, of iron is associated with the silica alumina complex.

It is of special interest to compare the composition of this profile, as given in table 39, of the Miami with the mean composition recalculated from the data for nine Miami profiles from various points in Indiana and Michigan by Holmes and Edgington (*10*). The mean composition of the A horizon is Al_2O_3. 3.33 SiO_2. 2.25 H_2O and for the B horizon Al_2O_3. 3.24 SiO_2. 2.27 H_2O.

There is, of course, no sharply defined division between the Gray-Brown Podzolic great group and the Red and Yellow Podzolic soils (lateritic soils). Data are available, however, from a number of profile examinations of soils which doubtless belong in the Gray-Brown Podzolic group. Among these are the mean of 7 profiles of the Leonardtown silt loam reported by Holmes (*9*); the Clinton, Muskingum, Vernon, and Kirvin soils, reported by Middleton, Slater and Byers (*15*); and the Susquehanna sandy loam reported by Baver and Scarseth (*3*). The mean values for the A horizons of these six soils expressed as in table 39 are: Al_2O_3. 2.92 SiO_2. 2.76 H_2O.

It is evident, therefore, if these six soils be taken as representative of the Gray-Brown Podzolic group, that the hypothetical colloid acid has a composition intermediate between the pyrophyllic acid and halloysitic acid. Whether these relations correspond to an intermediate colloid complex, as is assumed by some, or whether to a mixture of complexes, is not determinable from present data. Regardless of the view held as to the character of the constitution of the complex it seems clear that the Gray-Brown Podzolic group has a characteristic colloid complex. This is the case whether the iron-oxide component be regarded as largely free or largely combined.

The two lateritic soils considered in detail represent soils developed under very similar climatic conditions from different parent materials. In both, the silica-sesquioxide ratios lie well below 2, while the silica-alumina ratios are reasonably near to 2 if the whole profile is considered. If it be assumed that nearly, if not quite, all of the iron present is free ferric oxide, then the composition of the silica-alumina complex approaches as closely to the halloysitic acid composition as may be reasonably expected. As mentioned above, no sharp division is to be expected between the Gray-Brown Podzolic soils and the Red and Yellow soils of the South and Southwest. From the available profiles studied in this laboratory three may be selected to compare with the formulas given in table 39. These are the B horizon of the Davidson, reported by Brown and Byers (*4*); the A and B of the Nacogdoches, by Middleton, Slater, and Byers (*15*); and the mean of the A horizon of eight profiles of the Chester by Holmes and Edgington (*10*). The data for the A horizon of the Davidson are not available. The mean composition of the hypothetical colloid acid for these four soils is Al_2O_3. 1.96 SiO_2. 2.62 H_2O.

If the data presented for the lateritic soil colloids correctly represents the colloidal soil acid of this group its composition is close to halloysitic acid. It may be assumed that the less weathered colloids contain some colloid of higher silica-alumina ratio than 2, and in the more weathered colloids the composition approaches more closely that of the laterites.

The composition of the Columbiana colloid shown in table 39 cannot be directly compared with any like colloid studied in this laboratory. The same general relations are shown by the Nipe colloid reported by Anderson and Byers (*2*) but in that colloid organic matter and manganese were not determined.

The composition of the Podzol colloids as shown in table 39 represents the only cases of a water content of more than three formula weights where the color of the colloid indicates much free iron oxide. In the table the widely different A_1 and A_2 horizons are averaged.

If the composition of each section is expressed separately, the relations become:

For the Caribou, A_1 Al_2O_3. 3.47 SiO_2. 2.48 H_2O
A_2 Al_2O_3. 3.36 SiO_2. 2.53 H_2O
For the Au Train, A_1 Al_2O_3. 5.49 SiO_2. 9.51 H_2O
A_2 Al_2O_3. 5.65 SiO_2. 2.76 H_2O

The same type of relations is shown by the Emmet fine sandy loam reported by Denison (*7*) and for the Superior fine sandy loam and Becket loam reported by Anderson and Byers (*2*), but these are also subject to the same lack of quantatitive value as are the Caribou and Au Train profiles. The organic matter is more than twice as great as the combined water in the A_1 horizon of the Caribou colloid (table 27) and almost five times as great in the A_1 of the Au Train colloid (table 31). If, then, the known unsatisfactory character of the factor 1.724, be considered, the unsatisfactory character of the above results is readily understandable. It is clear, therefore, that no definite conclusions, except of a qualitative character, can be based upon the water relations of the inorganic colloid of soils in which the organic matter exceeds the combined water. Such considerations must await a satisfactory means of estimation of organic matter. It also follows that there is an element of uncertainty in all cases, due to this difficulty as well as to the other uncertainties mentioned on page 4.

In considering the assembled data of table 39 it appears that in general the water of combination of the soil acid is higher in the surface colloid than in the colloids of the lower portions of the profile. This relation is undoubtedly in part owing to the relatively higher organic content of the surface colloid, but is also in part due to the probable presence in the B and C horizon colloids of unweathered material in the colloid. If the general relation of hydrolysis is as outlined, hydrolysis of most minerals adds more water than corresponds to base present in unweathered materials.

GROUP DISTINCTIONS

What degree of validity is to be attached to the hypothetical considerations is open to question. There can be no question of the fact that the analyses presented supplemented by the examination of many other profiles show that each of the great groups presents a distinctive type of colloid. It would appear that the environmental conditions under which Chernozem soils develop produce the same general type of colloid characterized by high silica-sesquioxide and silica-alumina ratios, low silica-base ratios, and high pH values. The Prairie colloids are lower in all these respects than are those from Chernozem soils. The colloids of the Gray-Brown Podzolic group are characterized by silica-sesquioxide and silica-alumina ratios approximating in magnitude those of the Prairie soils and with a higher silica-base ratio. In part these higher values appear to be due to the presence of colloidal unweathered or partially weathered materials.

The Lateritic great group is characterized by a silica-sesquioxide ratio of less than 2, a silica-alumina ratio of approximately 2, a silica-base ratio which is very high as compared with previous groups, and by the presence of iron oxide in a free condition and apparently dehydrated. The colloid of the Laterite group has not been adequately investigated, but it appears to be characterized by the pres-

ence of a silica-sesquioxide ratio of less than one-half, a silica-alumina ratio of nearly 1, and by a very extreme paucity of bases.

The colloid of the Podzol great group is characterized by very high silica-sesquioxide and silica-alumina ratios in the A horizon and by strikingly lower values of these ratios in the B horizon. The most striking characteristic is therefore the fractionation of the colloid accumulated in the B horizon.

The colloids of all the great groups are characterized by an essentially constant water-alumina ratio.

It may be added that the broad distinctions just outlined are supplemented by less striking differences. Thus, the Chernozem and Lateritic great groups have a colloid which is remarkably constant for the whole profile. The Gray-Brown Podzolic group shows podzolic fractionation to less degree than the Podzols themselves. In all the groups characteristics seem to be largely independent of the present mineral sources.

Since the environmental conditions presumably responsible for the development of the colloid characteristics merge into one another in a geographical sense, it is to be expected that transitional soil profiles also exist.

SUMMARY

Detailed analytical data have been presented for 8 soil profiles representing 6 of the great groups of soils. These include mechanical and chemical analyses of the soils and chemical analyses of the colloids. Derived data from the analytical results are tabulated.

The results show that the colloids of the great groups of soils differ from each other, and that there exists a chemical basis for the characteristics manifested in the field. The Chernozems are characterized by high silica-sesquioxide and silica-alumina ratios and by uniformity of colloid composition throughout the profile. The Prairie colloids have distinctly lower silica ratios than the Chernozems but are essentially free from carbonates. The colloid profile is constant in composition. The Gray-Brown Podzolic colloids are not sharply different in silica ratios from the Prairie colloids but show more variation in profile. The lateritic and Laterite groups have low silica-alumina ratios but very high silica-base ratios. The Podzol soils reflect in colloid composition the extensive fractionation which has taken place within the profiles.

The analytical data have been correlated to develop a systematic relationship between the soil colloids independently of any assumptions with regard to the causes of these relationships.

The results have been discussed from the standpoint of the genetic relationships of the inorganic colloids and the light they throw on hypothetical considerations of colloidal acid composition. Modification and extension of previously published views are based on the present study and on comparisons with selected data from other sources. In these considerations the possible existence of five fundamental compounds resulting from the hydrolysis of minerals is postulated. In addition to the final hydrolytic products, aluminum hydroxide and ferric hydroxide, the hypothetical acids are assumed to have the composition (1) $3H_2O.Al_2O_3.6SiO_2$. (2) $3H_2O.Al_2O_3.4SiO_2$. (3) $3H_2O.Al_2O_3.2SiO_2$ and (4) $3H_2O.Al_2O_3.SiO_2$. The names suggested for these compounds are (1) montmorillonitic acid, (2) pyrophyllic acid, (3) halloysitic acid, and (4) allophanic acid, and are derived from

the clay minerals of approximately similar composition. It is emphasized that no single inorganic colloid can reasonably be expected to consist wholly of the derivatives of any one of these acids.

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EFFECT OF ALFALFA AND FARM MANURE ON YIELDS OF IRRIGATED CROPS IN THE GREAT PLAINS

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INTRODUCTION

It is essential to a successful irrigated agriculture that such a program of farm management be in effect that crop yields are maintained indefinitely and of a magnitude promising a profit on the enterprise. It has been often demonstrated by farmers, as well as by investigators, that, where staple farm crops are chiefly grown, this may be most effectively accomplished by crop rotation, including in the crop sequence either a leguminous crop, such as alfalfa, or the occasional application of stable manure. It has been found that most staple farm crops respond favorably to applications of stable manure. However, it is rarely available in adequate quantities to meet the requirements on irrigation projects where cash crops such as sugar beets, potatoes, and cotton are featured in the planting program. This condition has resulted in the inclusion of alfalfa, sweetclover, and certain other leguminous crops in the cropping program, because of the resulting benefits in the form of increased yields of subsequent crops. This practice has been followed so generally and with such beneficial effects on some crops under certain conditions that it is often believed to have more general and literal application than may be justified, although it is recognized that the inclusion of such leguminous crops as alfalfa in the cropping program has had a profoundly

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favorable effect in maintaining the productivity of the soil. More recent investigations have disclosed that serious losses have frequently resulted because of insufficient information relative to the effectiveness of leguminous crops as compared with applications of stable manure as aids in improving and maintaining soil productivity.

These as well as other agronomic problems confronting the settlers justified the establishment in 1910, by the Bureau of Plant Industry, of three field stations in the northern Great Plains as follows: (1) The Huntley station, located on the Huntley reclamation project, near the town of Huntley, in southeastern Montana; (2) the Belle Fourche station, located on the Belle Fourche reclamation project, near the town of Newell, in western South Dakota; (3) the Scotts Bluff station, located on the North Platte reclamation project, near the town of Mitchell, in western Nebraska. The conditions existing at these three locations are fairly representative of those found in the western part of the States of Nebraska and South Dakota and in adjoining States to the west and south as well as in a large portion of Montana where irrigation is practiced.

The average annual precipitation in this section of the northern Great Plains is about 14 inches. Consequently, the climate is essentially semiarid and irrigation is necessary if large crop yields are to be assured. The growing season between frosts is approximately 125 days, which permits the successful production of crops adapted to the more northern latitudes of the United States. The Scotts Bluff station has an elevation of 4,000 feet, while Belle Fourche and Huntley are approximately 3,000 feet above sea level.

The crops chiefly produced in the area are sugar beets, potatoes, alfalfa, sweetclover, corn, barley, oats, and wheat. For the past several years sugar beets have been the chief cash crop on the Huntley and Belle Fourche projects. On the North Platte project large acreages have been devoted to sugar beets, but during years when price prospects have appeared favorable substantial acreages of potatoes have been grown. Cereals are less extensively grown, their chief purpose being to supply the local feed requirements. There are extensive acreages of alfalfa on all three projects intended, in a large measure, to supply feed for livestock maintained on the farms, while the surplus is absorbed by local and adjoining markets. The acreage devoted to alfalfa has been stimulated still further because of the favorable effect this crop has had in increasing subsequent crop yields.

The soil at the Belle Fourche station is a heavy clay, known locally as "gumbo" and designated technically as Pierre clay in the United States Department of Agriculture, Bureau of Chemistry and Soils survey of the county. Such soils warm slowly in the spring, cannot be worked properly except when moisture conditions are favorable, and dry slowly particularly when temperatures are low. Cool, damp springs have so delayed planting or retarded plant growth that crop yields have been markedly depressed. It has been found that under such conditions vicissitudes of the climate from year to year have had a greater influence on crop yields than has occurred either at the Huntley or at the Scotts Bluff stations, which are located on less refractory soil types. The Pierre clay is developed from Pierre shale, a fissured and salt-bearing formation in which saline subsoil water accumulates from canal seepage.

The soil of the Huntley Field Station is a productive clay loam and lighter in character than that at the Belle Fourche station. In texture it is representative of extensive areas of the better lands under irrigation throughout the Northwest. It overlies a gravelly subsoil which is often filled with water under pressure from canal seepage.

The soil of the Scotts Bluff station is a friable fine sandy loam and is fairly productive when first broken from the native sod, but soon loses its productivity unless stable manure is applied or a leguminous crop is included in the cropping program. The soil responds very readily to various rotational treatments, such as the inclusion of alfalfa in the cropping program, and to applications of stable manure. Both the surface and subsoil take water readily, and there is sufficient elevation to provide adequate subsoil as well as surface drainage.

The irrigation supplies at the Huntley and Scotts Bluff Field Stations are of low salinity, while that of Belle Fourche is intermediate in this respect. The soils and subsoils at Belle Fourche contain a good deal of salt in spots; those at Huntley are less salty, though there are areas of saline soils on the project. At Scotts Bluff salinity of the soils is not an important factor except in low-lying areas near the North Platte River.

DESCRIPTION OF THE ROTATIONS

In 1912 a series of rotation experiments were inaugurated at these three field stations. At the time these investigations were included as a part of the program of the stations the object in view was to determine the cropping methods, crop sequences, and treatments, including applications of stable manure, best suited to improve and to maintain indefinitely the productivity of these lands. With the close of the year 1932 an opportunity was afforded to observe the various results obtained over a 21-year period. As the work has advanced a number of papers have been published relative to the results obtained (*1, 2, 3, 4, 5, 6, 7, 8, 9, 10*).[1]

Sugar beets, potatoes, and oats have been selected for the purpose of ascertaining to what extent alfalfa and applications of stable manure have influenced the yields of these crops in the different rotations on the three stations. In this series an opportunity is afforded of observing over a 21-year period (1) the influence of 2 years of alfalfa on the yields of these three crops in different sequences as compared with identical rotations not including alfalfa; (2) the extent to which the yields are affected when alfalfa is grown for 3 years; (3) how much yields have been stimulated by applications of stable manure; (4) the value of manure as compared with alfalfa in similar rotations; and (5) in two alfalfa rotations, 60 and 61, it is possible to observe the extent to which crop yields have been influenced by an application of stable manure every sixth year to a rotation including alfalfa. In all there are 21 pairs of rotations from which these results are obtained. In each pair the only difference is that one rotation includes alfalfa for 2 or 3 years while the other does not. In the cases where stable manure was applied and comparisons are made, each rotation included the same crops; one rotation received the manurial treatment while

[1] Italic numbers in parentheses refer to Literature Cited, p. 39.

the other did not. The crops involved, the sequences of the crops, and the indicated manurial treatment are as follows:

ROTATIONS WITHOUT ALFALFA COMPARED WITH THOSE WITH ALFALFA

20. Potatoes, sugar beets.
40. Potatoes, sugar beets, alfalfa, alfalfa.

22. Oats, sugar beets.
42. Oats, sugar beets, alfalfa, alfalfa.

24. Potatoes, oats.
44. Potatoes, oats, alfalfa, alfalfa.

22. Sugar beets, oats.
46. Sugar beets, oats, alfalfa, alfalfa.

28. Wheat, oats.
48. Wheat, oats, alfalfa, alfalfa.

30. Potatoes, oats, sugar beets.
60. Potatoes, oats, sugar beets, alfalfa, alfalfa, alfalfa.

31. Potatoes, oats (manure), sugar beets.
61. Potatoes, oats (manure), sugar beets, alfalfa, alfalfa, alfalfa.

32. Corn, oats, sugar beets.
62. Corn, oats, sugar beets, alfalfa, alfalfa, alfalfa.

34. Potatoes, sugar beets, oats.
64. Potatoes, sugar beets, oats, alfalfa, alfalfa, alfalfa.

ROTATIONS WITHOUT STABLE MANURE COMPARED WITH THOSE WITH MANURE

20. Potatoes, sugar beets.
21. Potatoes, sugar beets (manure).

22. Sugar beets, oats.
23. Sugar beets, oats (manure).

24. Potatoes, oats.
25. Potatoes, oats (manure).

30. Sugar beets, potatoes, oats.
31. Sugar beets, potatoes, oats (manure).

34. Oats, potatoes, sugar beets.
35. Oats (manure), potatoes, sugar beets.

60. Potatoes, oats, sugar beets, alfalfa, alfalfa, alfalfa.
61. Potatoes, oats (manure), sugar beets, alfalfa, alfalfa, alfalfa.

ROTATIONS WITH MANURE COMPARED WITH THOSE WITHOUT MANURE BUT INCLUDING ALFALFA

21. Sugar beets (manure), potatoes.
40. Potatoes, sugar beets, alfalfa, alfalfa.

23. Sugar beets, oats (manure).
42. Sugar beets, alfalfa, alfalfa, oats.

23. Sugar beets, oats (manure).
46. Sugar beets, oats, alfalfa, alfalfa.

25. Oats (manure), potatoes.
44. Oats, alfalfa, alfalfa, potatoes.

31. Sugar beets, potatoes, oats (manure).
60. Potatoes, oats, sugar beets, alfalfa, alfalfa, alfalfa.

35. Potatoes, sugar beets, oats (manure).
64. Potatoes, sugar beets, oats, alfalfa, alfalfa, alfalfa.

These series of rotations at present consist of 42 different cropping systems at Belle Fourche, 43 at Huntley, and 48 at Scotts Bluff. In connection with the other information being accumulated as a result

of these rotation experiments at the 3 stations it is possible in the following tables to observe the effect of alfalfa on the yields of sugar beets in 18 different combinations, the effect on sugar beets of applications of 12 tons of stable manure in 13 rotations, and the extent that sugar-beet yields have been influenced by stable manure as compared with alfalfa in 12 rotations. In the tables giving the results with potatoes there are involved the effect of alfalfa in 14 rotations, the applications of stable manure in 14, and the value of stable manure as compared with alfalfa in 11. With oats there are available 19 pairs of rotations where the effects of alfalfa on the yields are recorded, 14 of which indicate the value of stable manure, and 12 where the merits of alfalfa and stable manure are compared.

CULTURAL PRACTICES

In conducting these investigations throughout the 21-year period it has been the aim to adopt the best cultural practices used in the local community. Seed of the same variety of each crop is used each season at any one station, although in a few instances throughout the period it has been found advisable to change the variety. It is not believed that this substitution of varieties in the few instances it has occurred has influenced the results appreciably. The cultural treatments applied and the planting dates were as nearly identical at each station as conditions would permit.

At the Belle Fourche station all plots planted to sugar beets or potatoes were fall-plowed and left rough throughout the winter. All plots preceded by a cultivated crop were not plowed but were thoroughly disked in the spring preparatory to seeding. In the cases where oats followed alfalfa or another cereal the land was fall-plowed. Plots in alfalfa to be followed by sugar beets or potatoes were plowed in the fall, and in the spring the ground was worked with a spring-tooth harrow or duck-foot cultivator to kill as many of the plants as possible. In those rotations receiving farm manure the manure was plowed under.

At the Huntley station all plots to be planted to sugar beets or potatoes were fall-plowed to a depth of about 8 inches and left rough throughout the winter. In the instances where oats followed a cultivated crop the land was not plowed but was double-disked in the spring preparatory to planting. Where oats followed an uncultivated crop the land was fall-plowed. In the event alfalfa was the preceding crop the alfalfa was crowned, that is, the land was plowed to a depth of approximately 4 inches and after about a week or 10 days it was worked with a spring-tooth harrow and later plowed to the usual depth. In those rotations so treated the manure was applied before the second plowing.

During the first years of the experiment the practice at the Scotts Bluff station was to plant sugar beets and potatoes on fall-plowed land. In recent years these two crops have been planted on spring-plowed land except in rotations 24 and 25 where the oat-stubble land is still fall-plowed for potatoes. Where potatoes follow alfalfa the early practice was to fall-crown the alfalfa and then plow to a greater depth the following spring. Now the alfalfa land for potatoes is plowed in the spring after growth starts. Where oats follow sugar beets, corn, or potatoes the land was spring-disked before seeding.

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When oats follow alfalfa the land was plowed in the spring shortly before seeding. Manure was applied just before plowing.

At all three of these field stations farm manure was applied at the rate of 12 tons per acre. In each case the plots are one-fourth acre in size and are laid out in series separated by 40-foot roads and the plots in the series by a 5-foot alley. At Belle Fourche the plots are 264 feet long by 41.25 feet wide; those at Huntley are 227 feet long by 48 feet wide; while those at Scotts Bluff are 132 feet long by 82.5 feet wide. Each rotation is so arranged that each crop in each rotation is grown each year. To carry out this plan it is necessary to have as many plots as there are years in the cycle of each rotation. By the adoption of this method it is possible to compare each year the yields from the same crops grown in each of the different rotations.

The responsibility for supervising the proper conduct of the field operations of these rotation experiments, taking the field notes, and compiling the data has been placed upon a station superintendent at each of the three locations.[2]

PRESENTATION OF THE DATA

In assembling the data for the 21 years the mean yields by 7-year periods are given rather than the detailed material required for recording individual annual yields. In each instance crop yields from rotations having the same major crops are compared, and the increase or decrease which may be attributed to the treatment is determined. The only difference is that one cropping system has an application of farm manure during its cycle or alfalfa is included, whereas the other has neither of these treatments. In the preparation of the tables and discussion it was found desirable to arrange the data according to crops rather than treatments. By this method an opportunity is afforded for observing directly the extent that yields have been influenced by application of farm manure, the inclusion of alfalfa in the cropping program, as well as direct comparisons of the effect of alfalfa and of manure.

EFFECT OF MANURE ON YIELDS OF SUGAR BEETS

In table 1 is recorded the extent to which applications of 12 tons of farm manure have influenced the yields of sugar beets, expressed in tons per acre by 7-year periods. In all instances the crop sequences and treatments have been the same, the only difference being that one rotation in each pair received the manurial treatment, whereas the other did not. The manure was applied to the land immediately preceding the beet crop except in the case of 2-year rotation 21 where the treatment was applied preceding the potatoes.

[2] At Belle Fourche, Beyer Aune has been superintendent since 1909. J. B. Lenty, N. L. Mattice, and George T. Ratliffe have aided at different times. Dan Hansen has been station superintendent at Huntley since 1910. At times during the period covered by these investigations he has been aided by J. M. Spain, J. W. Knorr, E. G. Noble, and D. A. Savage. From 1910 to 1916 Fritz Knorr was station superintendent at Scotts Bluff. James A. Holden was in charge of the rotations from 1912 until 1916, and since 1916 he has been station superintendent and continued the responsibility for these investigations.

TABLE 1.—*Effect of manure on the yields of sugar beets (tons per acre) at the Belle Fourche, Huntley, and Scotts Bluff Field Stations by 7-year periods, 1912–32*

BELLE FOURCHE

Rotation no.	Crop sequence	1912–18	1919–25	1926–32
		Tons	*Tons*	*Tons*
21	Sugar beets (manure), potatoes	12.9	17.4	16.9
20	Sugar beets, potatoes	11.0	13.8	11.1
	Difference in favor of manure	1.9	3.6	5.8
23	Sugar beets, oats (manure)	11.2	16.5	15.4
22	Sugar beets, oats	9.4	12.4	10.4
	Difference in favor of manure	1.8	4.1	5.0
31	Sugar beets, potatoes, oats (manure)	11.5	12.7	11.9
30	Sugar beets, potatoes, oats	7.7	8.4	6.6
	Difference in favor of manure	3.8	4.3	5.3
61	Sugar beets, alfalfa, alfalfa, alfalfa, potatoes, oats (manure)	10.9	13.6	15.1
60	Sugar beets, alfalfa, alfalfa, alfalfa, potatoes, oats	10.1	11.3	10.5
	Difference in favor of manure	.8	2.3	4.6

HUNTLEY

21	Sugar beets (manure), potatoes	13.8	16.2	18.0
20	Sugar beets, potatoes	12.3	12.4	10.4
	Difference in favor of manure	1.5	3.8	7.6
23	Sugar beets, oats (manure)	12.4	13.5	16.8
22	Sugar beets, oats	11.0	9.0	5.6
	Difference in favor of manure	1.4	4.5	11.2
31	Sugar beets, potatoes, oats (manure)	10.8	13.3	17.6
30	Sugar beets, potatoes, oats	7.4	8.7	8.0
	Difference in favor of manure	3.4	4.6	9.6
35	Sugar beets, oats (manure), potatoes	[1] 12.2	15.3	15.9
34	Sugar beets, oats, potatoes	[1] 11.5	12.4	6.3
	Difference in favor of manure	.7	2.9	9.6
61	Sugar beets, alfalfa, alfalfa, alfalfa, potatoes, oats (manure)	13.4	16.7	17.7
60	Sugar beets, alfalfa, alfalfa, alfalfa, potatoes, oats	10.5	14.0	13.6
	Difference in favor of manure	2.9	2.7	4.1

SCOTTS BLUFF

21	Sugar beets (manure), potatoes	15.4	17.5	17.4
20	Sugar beets, potatoes	13.4	10.3	8.6
	Difference in favor of manure	2.0	7.2	8.8
23	Sugar beets, oats (manure)	18.3	18.1	18.1
22	Sugar beets, oats	13.0	9.6	8.6
	Difference in favor of manure	5.3	8.5	9.5
31	Sugar beets, potatoes, oats (manure)	18.5	17.2	18.3
30	Sugar beets, potatoes, oats	12.6	10.7	8.7
	Difference in favor of manure	5.9	6.5	.6
61	Sugar beets, alfalfa, alfalfa, alfalfa, potatoes, oats (manure)	19.2	19.9	18.4
60	Sugar beets, alfalfa, alfalfa, alfalfa, potatoes. oats	14.4	15.8	13.3
	Difference in favor of manure	4.8	4.1	5.1

[1] For the period 1916–18 only.

In every 7-year period at all three stations the benefits from the application of farm manure were positive, the increased yields of the treated over the untreated rotations ranging from a minimum of 0.7 ton to a maximum of 11.2 tons per acre. When the trend of these yields is considered by 7-year periods it will be observed that there is a definite tendency for the differences to increase progressively, the only exception being the 6-year rotations 60 and 61. However, even in this instance where 3 years of alfalfa was included in the cropping program, an application of manure stimulated the yields of beets from a minimum of 0.8 ton to a maximum of 5.1 tons per acre. At the Scotts Bluff station the highest yields have been consistently those harvested from the alfalfa-manured rotation 61, where the yields ranged from a minimum of 18.4 to a maximum of 19.9 tons of sugar beets to the acre. In considering the yields from the untreated rotations it is apparent that when the yields from three 7-year periods are considered, the sugar-beet yields are scarcely being maintained at Belle Fourche and are decidedly reduced at Scotts Bluff and Huntley. It is emphasized that a better opportunity is afforded for observing yield trends of the treated compared to the untreated rotations by considering only the differences as the influence on yields of the seasonal variations is eliminated. Even when the hazards of a varying moisture supply are not a factor, as has been the case under the irrigated conditions where these investigations have been conducted, often one or more seasons have been unfavorable for obtaining satisfactory yields of beets during a 7-year period, which has depressed the mean; whereas throughout other cycles the seasons have been generally more favorable. This is apparent when the detailed sugar-beet yields for the second 7-year period at the Belle Fourche station are considered when the years 1922, 1923, and 1925 were very favorable for high-average yields as compared with average yearly yields during the other two periods.

EFFECT OF ALFALFA ON YIELDS OF SUGAR BEETS

Table 2 gives the detailed yields of sugar beets by 7-year periods for the three stations, indicating the influence of alfalfa on the yields of beets. In all rotations except no. 46 one or more crops intervened before the sugar beets were grown. The planting of sugar beets immediately following alfalfa ordinarily is not to be recommended, because, owing to the prevalence of the damping-off fungus, commonly called black root, it is difficult to obtain a satisfactory stand.

At the Belle Fourche station in all three rotations where alfalfa was grown for 2 years, only one period is found where beet yields have been stimulated as a result of including alfalfa. This occurred in the third 7-year period in rotation 40, where the increase was 0.7 ton per acre. On the other hand, 3 years of alfalfa in 6-year rotations 60, 61, and 62 reacted favorably on the yields of beets but in rotation 64 yields were reduced. It should be noted that these two rotations were not included in the series until 1917 and consequently are for 16 years only, whereas yields from all other 6-year rotations at this station are for the full 21 years. The most consistently favorable results have been obtained from rotation 60 when compared with rotation 30. While the sugar-beet yields from rotation 60 are not high, yet when compared with no. 30, which is similar except that it does not include

alfalfa, the increases in the yields of beets for the three 7-year periods are 2.4, 2.9, and 3.9 tons per acre, respectively.

TABLE 2.—*Effect of alfalfa on the yields of sugar beets (tons per acre) at the Belle Fourche, Huntley, and Scotts Bluff Field Stations by 7-year periods, 1912–32*

BELLE FOURCHE

Rotation no.	Crop sequence	1912–18	1919–25	1926–32
		Tons	*Tons*	*Tons*
40	Sugar beets, alfalfa, alfalfa, potatoes	10.6	13.0	11.8
20	Sugar beets, potatoes	11.0	13.8	11.1
	Difference in favor of alfalfa	−.4	−.8	.7
42	Sugar beets, alfalfa, alfalfa, oats	8.5	9.6	9.2
22	Sugar beets, oats	9.4	12.4	10.4
	Difference in favor of alfalfa	−.9	−2.8	−1.2
46	Sugar beets, oats, alfalfa, alfalfa	[1] 9.7	7.0	6.7
22	Sugar beets, oats	[1] 10.7	12.4	10.4
	Difference in favor of alfalfa	−1.0	−5.4	−3.7
60	Sugar beets, alfalfa, alfalfa, alfalfa, potatoes, oats	10.1	11.3	10.5
30	Sugar beets, potatoes, oats	7.7	8.4	6.6
	Difference in favor of alfalfa	2.4	2.9	3.9
61	Sugar beets, alfalfa, alfalfa, alfalfa, potatoes, oats (manure)	10.9	13.6	15.1
31	Sugar beets, potatoes, oats (manure)	11.5	12.7	11.9
	Difference in favor of alfalfa	−.6	.9	3.2
62	Sugar beets, alfalfa, alfalfa, alfalfa, corn, oats	8.1	8.8	9.8
32	Sugar beets, corn, oats	6.9	7.0	6.0
	Difference in favor of alfalfa	1.2	1.8	3.8
64	Sugar beets, oats, alfalfa, alfalfa, alfalfa, potatoes	[1] 12.2	13.4	10.9
34	Sugar beets, oats, potatoes	[1] 13.3	14.8	11.5
	Difference in favor of alfalfa	−1.1	−1.4	−.6

HUNTLEY

40	Sugar beets, alfalfa, alfalfa, potatoes	12.5	12.5	9.3
20	Sugar beets, potatoes	12.3	12.4	10.4
	Difference in favor of alfalfa	.2	.1	−1.1
42	Sugar beets, alfalfa, alfalfa, oats	10.2	11.5	7.5
22	Sugar beets, oats	11.0	9.0	5.6
	Difference in favor of alfalfa	−.8	2.5	1.9
46	Sugar beets, oats, alfalfa, alfalfa	[2] 10.6	11.6	5.7
22	Sugar beets, oats	[2] 10.9	9.0	5.6
	Difference in favor of alfalfa	−.3	2.6	.1
60	Sugar beets, alfalfa, alfalfa, alfalfa, potatoes, oats	10.5	14.0	13.6
30	Sugar beets, potatoes, oats	7.4	8.7	8.0
	Difference in favor of alfalfa	3.1	5.3	5.6
61	Sugar beets, alfalfa, alfalfa, alfalfa, potatoes, oats (manure)	13.4	16.7	17.7
31	Sugar beets, potatoes, oats (manure)	10.8	13.3	17.6
	Difference in favor of alfalfa	2.6	3.4	.1
64	Sugar beets, oats, alfalfa, alfalfa, alfalfa, potatoes	[2] 11.6	14.2	10.1
34	Sugar beets, oats, potatoes	[2] 11.5	12.4	6.3
	Difference in favor of alfalfa	.1	1.8	3.8

[1] For the period 1917–18 only.

[2] For the period 1916–18 only.

TABLE 2.—*Effect of alfalfa on the yields of sugar beets (tons per acre) at the Belle Fourche, Huntley, and Scotts Bluff Field Stations by 7-year periods, 1912–32*—Continued

SCOTTS BLUFF

Rotation no.	Crop sequence	1912–18	1919–25	1926–32
		Tons	*Tons*	*Tons*
40	Sugar beets, alfalfa, alfalfa, potatoes	18.2	17.8	14.9
20	Sugar beets, potatoes	13.4	10.3	8.6
	Difference in favor of alfalfa	4.8	7.5	6.3
42	Sugar beets, alfalfa, alfalfa, oats	15.8	16.0	15.3
22	Sugar beets, oats	13.0	9.6	8.6
	Difference in favor of alfalfa	2.8	6.4	6.7
60	Sugar beets, alfalfa, alfalfa, potatoes, oats	14.4	15.8	13.3
30	Sugar beets, potatoes, oats	12.6	10.7	8.7
	Difference in favor of alfalfa	1.8	5.1	4.6
61	Sugar beets, alfalfa, alfalfa, alfalfa, potatoes, oats (manure)	19.2	19.9	18.4
31	Sugar beets, potatoes, oats (manure)	18.5	17.2	18.3
	Difference in favor of alfalfa	.7	2.7	.1
62	Sugar beets, alfalfa, alfalfa, alfalfa, corn, oats	14.5	14.9	13.0
32	Sugar beets, corn, oats	12.3	10.3	9.2
	Difference in favor of alfalfa	2.2	4.6	3.8

At the Huntley Field Station the influence of alfalfa on the yields of sugar beets was somewhat more favorable, as is evidenced by comparisons between rotations including alfalfa with those not so treated. This condition is definitely more apparent in the 6-year rotations which include 3 years of alfalfa. With the exception of the 31 and 61 manured combinations, the differences in favor of alfalfa for the three 7-year periods increased progressively. These results indicate that applications of farm manure are having a cumulatively favorable influence on the yields of beets in rotation 31; although applications of both manure and alfalfa in a 6-year rotation may not be economically justified, as is evidenced by the differences in the yields between rotations 61 and 31 for the last 7-year period. In the case of all three 4-year rotations having only 2 years of alfalfa, the yields for the last 7-year period are materially less than those obtained for the second period, and when the mean of the difference is determined for this period there is but 0.3 ton per acre in favor of the rotations including alfalfa. On the other hand, the mean of the differences for the rotations having 3 years of alfalfa for the same period is 3.2 tons per acre in favor of the rotations including alfalfa.

At the Scotts Bluff station the effect of alfalfa on the yields of sugar beets has been quite different from that obtained at the other two stations. In considering the differences in yields in the five combinations, beneficial effects have been obtained in every period as a result of including alfalfa in the cropping program. This is particularly apparent in the rotations including 2 years of alfalfa. However, as has occurred at Belle Fourche and at Huntley, the yields of beets for the last 7 years from both the 4-year rotations are less than for the previous period.

EFFECT OF MANURE AS COMPARED WITH ALFALFA ON YIELDS OF SUGAR BEETS

Table 3 affords a direct comparison of the effect of stable manure and of alfalfa on the yields of sugar beets. In all instances except in rotations 21 and 35 manure was applied immediately preceding the beet crop, and it may be assumed that the stimulating effect on beet yields would be more pronounced than would have occurred had an intervening crop such as potatoes been grown. On the other hand, except in the case of rotation 46, at Belle Fourche and at Huntley 1 or more intervening crops were grown following alfalfa and preceding beets, and 2 intervening crops occur in rotation 60 at all 3 stations.

TABLE 3.—*Effect of manure and alfalfa on yields of sugar beets (tons per acre) at the Belle Fourche, Huntley, and Scotts Bluff Field Stations by 7-year periods, 1912–32*

BELLE FOURCHE

Rotation no.	Crop sequence	1912–18	1919–25	1926–32
		Tons	*Tons*	*Tons*
21	Sugar beets (manure), potatoes	12.9	17.4	16.9
40	Sugar beets, alfalfa, alfalfa, potatoes	10.6	13.0	11.8
	Difference in favor of manure	2.3	4.4	5.1
23	Sugar beets, oats (manure)	11.2	16.5	15.4
42	Sugar beets, alfalfa, alfalfa, oats	8.5	9.6	9.2
	Difference in favor of manure	2.7	6.9	6.2
23	Sugar beets, oats (manure)	[1] 16.3	16.5	15.4
46	Sugar beets, oats, alfalfa, alfalfa	[1] 9.7	7.0	6.7
	Difference in favor of manure	6.6	9.5	8.7
31	Sugar beets, potatoes, oats (manure)	11.5	12.7	11.9
60	Sugar beets, alfalfa, alfalfa, alfalfa, potatoes, oats	10.1	11.3	10.5
	Difference in favor of manure	1.4	1.4	1.4
35	Sugar beets, oats (manure), potatoes	[1] 16.5	16.4	13.5
64	Sugar beets, oats, alfalfa, alfalfa, alfalfa, potatoes	[1] 12.2	13.4	10.9
	Difference in favor of manure	4.3	3.0	2.6

HUNTLEY

21	Sugar beets (manure), potatoes	13.8	16.2	18.0
40	Sugar beets, alfalfa, alfalfa, potatoes	12.5	12.5	9.3
	Difference in favor of manure	1.3	3.7	8.7
23	Sugar beets, oats (manure)	[2] 12.0	13.5	16.8
46	Sugar beets, oats, alfalfa, alfalfa	[2] 10.6	11.6	5.7
	Difference in favor of manure	1.4	1.9	11.1
31	Sugar beets, potatoes, oats (manure)	10.8	13.3	17.6
60	Sugar beets, alfalfa, alfalfa, alfalfa, potatoes, oats	10.5	14.0	13.6
	Difference in favor of manure	.3	−.7	4.0
35	Sugar beets, oats (manure), potatoes	[2] 12.2	15.3	15.9
64	Sugar beets, oats, alfalfa, alfalfa, alfalfa, potatoes	[2] 11.6	14.2	10.1
	Difference in favor of manure	.6	1.1	5.8

[1] For the period 1917–18 only.
[2] For the period 1916–18 only.

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TABLE 3.—*Effect of manure and alfalfa on yields of sugar beets (tons per acre) at the Belle Fourche, Huntley, and Scotts Bluff Field Stations by 7-year periods, 1912–32*—Continued

SCOTTS BLUFF

Rotation no.	Crop sequence	1912–18	1919–25	1926–32
		Tons	*Tons*	*Tons*
21	Sugar beets (manure), potatoes	15.4	17.5	17.4
40	Sugar beets, alfalfa, alfalfa, potatoes	18.2	17.8	14.9
	Difference in favor of manure	−2.8	−.3	2.5
23	Sugar beets, oats (manure)	18.3	18.1	18.1
42	Sugar beets, alfalfa, alfalfa, oats	15.8	16.0	15.3
	Difference in favor of manure	2.5	2.1	2.8
31	Sugar beets, potatoes, oats (manure)	18.5	17.2	18.3
60	Sugar beets, alfalfa, alfalfa, alfalfa, potatoes, oats	14.4	15.8	13.3
	Difference in favor of manure	4.1	1.4	5.0

The superiority of farm manure as compared with alfalfa is clearly apparent in table 3. For the last 7-year period manure has stimulated the yields of beets in excess of alfalfa, ranging from a minimum of 1.4 tons to a maximum of 11.1 tons per acre, with a mean increase of 5.3 tons. By individual stations, the mean superiority of manure over alfalfa for the same period is for Belle Fourche 4.8, for Huntley 7.4, and for Scotts Bluff 3.4 tons per acre. It has been shown that better results with sugar beets have occurred when at least one crop removed from alfalfa, preferably with a cultivated crop similar to potatoes intervening. Such a case occurs in rotation 64 at the Belle Fourche and Huntley stations. Even under such conditions when compared with rotation 35, with manure applied to the potatoes and the sugar beets immediately following, the superiority of the manurial treatment is apparent particularly for the last two 7-year periods.

EFFECT OF MANURE ON YIELDS OF POTATOES

The extent that farm manure influenced the yields of potatoes is indicated in table 4, which shows the yields and differences from comparable rotations. In only three instances was the manure applied directly preceding the potatoes; these were rotations 21, 25, and 35. In all other cases where 2- and 3-year rotations were involved the manure was applied to the sugar beets followed by potatoes. In rotation 61 the manure was applied to the sugar beets which were followed by 3 years of alfalfa, and then the potatoes were grown.

A comparison of the three periods indicates that there is an apparent tendency for applications of farm manure to increase the yields of potatoes at all three stations with the exception of the 60 and 61 rotations. In these 2 rotations not only are there 3 years of alfalfa preceding the potato crop, but 1 year of sugar beets and 3 years of alfalfa occur subsequent to the manurial treatment and before the potatoes are grown. These results indicate that stable manure applied to this rotation did not appreciably increase the yields of potatoes at any of the stations nor for any of the three 7-year periods. However, when the yields from rotation 31 are compared with those from rotation 30 at Huntley it appears that the manurial treatment has had a negative value for the first two 7-year periods.

TABLE 4.—*Effect of manure on yields of potatoes (bushels per acre) at the Belle Fourche, Huntley, and Scotts Bluff Field Stations by 7-year periods, 1912–32*

BELLE FOURCHE

Rotation no.	Crop sequence	1912–18	1919–25	1926–32
		Bushels	*Bushels*	*Bushels*
21	Potatoes, sugar beets (manure)	154	188	145
20	Potatoes, sugar beets	121	100	88
	Difference in favor of manure	33	88	57
25	Potatoes, oats (manure)	134	164	149
24	Potatoes, oats	115	138	116
	Difference in favor of manure	+19	26	33
31	Potatoes, oats (manure), sugar beets	149	188	157
30	Potatoes, oats, sugar beets	103	133	114
	Difference in favor of manure	46	55	43
35	Potatoes, sugar beets, oats (manure)	----------	210	159
34	Potatoes, sugar beets, oats	----------	159	139
	Difference in favor of manure	----------	51	20
61	Potatoes, oats (manure), sugar beets, alfalfa, alfalfa, alfalfa	114	140	133
60	Potatoes, oats, sugar beets, alfalfa, alfalfa, alfalfa	113	145	140
	Difference in favor of manure	1	−5	−7

HUNTLEY

21	Potatoes, sugar beets (manure)	279	200	249
20	Potatoes, sugar beets	266	185	138
	Difference in favor of manure	13	15	111
25	Potatoes, oats (manure)	355	292	292
24	Potatoes, oats	258	167	127
	Difference in favor of manure	97	125	165
31	Potatoes, oats (manure), sugar beets	200	147	182
30	Potatoes, oats, sugar beets	209	160	160
	Difference in favor of manure	−9	−13	22
35	Potatoes, sugar beets, oats (manure)	[1] 306	296	292
34	Potatoes, sugar beets, oats	[1] 317	247	177
	Difference in favor of manure	−11	49	115
61	Potatoes, oats (manure), sugar beets, alfalfa, alfalfa, alfalfa	333	290	323
60	Potatoes, oats, sugar beets, alfalfa, alfalfa, alfalfa	297	275	299
	Difference in favor of manure	36	15	24

SCOTTS BLUFF

21	Potatoes, sugar beets (manure)	195	224	276
20	Potatoes, sugar beets	170	130	149
	Difference in favor of manure	25	94	130
25	Potatoes, oats (manure)	224	233	287
24	Potatoes, oats	178	143	145
	Difference in favor of manure	46	90	142
31	Potatoes, oats (manure), sugar beets	223	244	312
30	Potatoes, oats, sugar beets	205	163	194
	Difference in favor of manure	18	81	118
61	Potatoes, oats (manure), sugar beets, alfalfa, alfalfa, alfalfa	290	320	348
60	Potatoes, oats, sugar beets, alfalfa, alfalfa, alfalfa	273	295	329
	Difference in favor of manure	17	25	19

[1] For the period 1916–18 only.

EFFECT OF ALFALFA ON YIELDS OF POTATOES

The influence of alfalfa on the yields of potatoes at the three stations in 14 instances is recorded in table 5. The potatoes immediately follow the alfalfa crop in all the rotations compared; hence the potato yields from the different combinations are directly comparable.

TABLE 5.—*Effect of alfalfa on the yield of potatoes (bushels per acre) at the Belle Fourche, Huntley, and Scotts Bluff Field Stations by 7-year periods, 1912–32*

BELLE FOURCHE

Rotation no.	Crop sequence	1912–18	1919–25	1926–32
		Bushels	*Bushels*	*Bushels*
40	Potatoes, sugar beets, alfalfa, alfalfa	116	155	123
20	Potatoes, sugar beets	121	100	88
	Difference in favor of alfalfa	−5	55	35
44	Potatoes, oats, alfalfa, alfalfa	139	180	167
24	Potatoes, oats	115	138	116
	Difference in favor of alfalfa	24	42	51
60	Potatoes, oats, sugar beets, alfalfa, alfalfa, alfalfa	113	145	140
30	Potatoes, oats, sugar beets	103	133	114
	Difference in favor of alfalfa	10	12	26
61	Potatoes, oats (manure), sugar beets, alfalfa, alfalfa, alfalfa	114	140	133
31	Potatoes, oats (manure), sugar beets	149	188	157
	Difference in favor of alfalfa	−35	−48	−24
64	Potatoes, sugar beets, oats, alfalfa, alfalfa, alfalfa	----------	112	130
34	Potatoes, sugar beets, oats	----------	159	139
	Difference in favor of alfalfa	----------	−47	−9

HUNTLEY

40	Potatoes, sugar beets, alfalfa, alfalfa	269	259	272
20	Potatoes, sugar beets	266	185	138
	Difference in favor of alfalfa	3	74	134
44	Potatoes, oats, alfalfa, alfalfa	208	181	216
24	Potatoes, oats	258	167	127
	Difference in favor of alfalfa	−50	14	89
60	Potatoes, oats, sugar beets, alfalfa, alfalfa, alfalfa	297	275	299
30	Potatoes, oats, sugar beets	209	160	160
	Difference in favor of alfalfa	88	115	139
61	Potatoes, oats (manure), sugar beets, alfalfa, alfalfa, alfalfa	333	290	323
31	Potatoes, oats (manure), sugar beets	200	147	182
	Difference in favor of alfalfa	133	143	141
64	Potatoes, sugar beets, oats, alfalfa, alfalfa, alfalfa	[1] 308	272	343
34	Potatoes, sugar beets, oats	[1] 317	247	177
	Difference in favor of alfalfa	−9	25	166

[1] For the period 1916–18 only.

TABLE 5.—*Effect of alfalfa on the yield of potatoes (bushels per acre) at the Belle Fourche, Huntley, and Scotts Bluff Field Stations by 7-year periods, 1912–32*—Continued

SCOTTS BLUFF

Rotation no.	Crop sequence	1912–18	1919–25	1926–32
		Bushels	*Bushels*	*Bushels*
40	Potatoes, sugar beets, alfalfa, alfalfa	257	296	279
20	Potatoes, sugar beets	170	130	149
	Difference in favor of alfalfa	87	166	130
44	Potatoes, oats, alfalfa, alfalfa	286	264	270
24	Potatoes, oats	178	143	145
	Difference in favor of alfalfa	108	121	125
60	Potatoes, oats, sugar beets, alfalfa, alfalfa, alfalfa	273	295	329
30	Potatoes, oats, sugar beets	205	163	194
	Difference in favor of alfalfa	68	132	135
61	Potatoes, oats (manure), sugar beets, alfalfa, alfalfa, alfalfa	290	320	348
31	Potatoes, oats (manure), sugar beets	223	244	312
	Difference in favor of alfalfa	67	76	36

The results recorded in table 5 indicate that alfalfa increased the yields of potatoes materially for the 3 periods and in all 4 combinations at the Scotts Bluff station. At this station the smallest increase of 36 bushels per acre occurred in the 61 and 31 combinations, and the highest yields for the 3 periods were obtained from rotation 61, which has alfalfa and, in addition, an application of manure once during its 6-year cycle. At the Huntley station there were no consistent differences in favor of alfalfa during the first 7-year period. On the other hand, the differences are all in favor of alfalfa for the second and third 7-year periods for the 5 comparisons. Contrary to the results obtained at Scotts Bluff, the most favorable effects from alfalfa at the Huntley station occurred in the manured 61 and 31 rotations, where the yield differences in favor of alfalfa are 133, 143, and 141 bushels per acre, respectively, for the 3 periods. The results obtained at the Belle Fourche station have not been consistent, although the differences are in favor of alfalfa for the first 3 comparisons made for the second and third 7-year period. In comparing rotation 61 with rotation 31 at the Belle Fourche station, both of which had applications of manure, but the former having 3 years of alfalfa, the results indicate that the manurial treatment alone was more effective in maintaining the yields of potatoes at this station than was a combination of manure and alfalfa. When the mean yields from the 3 stations are compared it is evident that the heavier soils of the Belle Fourche station are not as favorable for large potato yields as are the somewhat lighter soils of the other 2 stations. Not only have the yields of potatoes been relatively low at Belle Fourche, but over the 21-year period the annual yields have fluctuated within wide limits, chiefly because of unfavorable weather. When such conditions occur the injury sustained by the different plots is often variable, and the yields recorded for such seasons do not reflect accurately the differences which under normal conditions may be attributed to rotational treatments.

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EFFECT OF MANURE AS COMPARED WITH ALFALFA ON YIELDS OF POTATOES

In table 6 with 11 pairs of rotations it is possible to observe the effect of farm manure as compared with alfalfa on the yields of potatoes in similar rotations at the 3 stations. In rotations 21, 25, and 35, the manure was applied to the potato crop. In rotation 31 it was applied to sugar beets which crop immediately preceded potatoes in the rotation.

TABLE 6.—*Effect of manure as compared with alfalfa on yields of potatoes (bushels per acre) at the Belle Fourche, Huntley, and Scotts Bluff Field Stations by 7-year periods, 1912–32*

BELLE FOURCHE

Rotation no.	Crop sequence	1912–18	1919–25	1926–32
		Bushels	*Bushels*	*Bushels*
40	Potatoes, sugar beets, alfalfa, alfalfa	116	155	123
21	Potatoes, sugar beets (manure)	154	188	145
	Difference in favor of alfalfa	−38	−33	−22
44	Potatoes, oats, alfalfa, alfalfa	139	180	167
25	Potatoes, oats (manure)	134	164	149
	Difference in favor of alfalfa	5	16	18
60	Potatoes, oats, sugar beets, alfalfa, alfalfa, alfalfa	113	145	140
31	Potatoes, oats (manure), sugar beets	149	188	157
	Difference in favor of alfalfa	−36	−43	−17
64	Potatoes, sugar beets, oats, alfalfa, alfalfa, alfalfa	----------	112	130
35	Potatoes, sugar beets, oats (manure)	----------	210	159
	Difference in favor of alfalfa	----------	−98	−29

HUNTLEY

40	Potatoes, sugar beets, alfalfa, alfalfa	269	259	272
21	Potatoes, sugar beets (manure)	279	200	249
	Difference in favor of alfalfa	−10	59	23
44	Potatoes, oats, alfalfa, alfalfa	208	181	216
25	Potatoes, oats (manure)	355	292	292
	Difference in favor of alfalfa	−147	−111	−76
60	Potatoes, oats, sugar beets, alfalfa, alfalfa, alfalfa	297	275	299
31	Potatoes, oats (manure), sugar beets	200	147	182
	Difference in favor of alfalfa	97	128	117
64	Potatoes, sugar beets, oats, alfalfa, alfalfa, alfalfa	[1] 308	272	343
35	Potatoes, sugar beets, oats (manure)	[1] 306	296	292
	Difference in favor of alfalfa	2	−24	51

SCOTTS BLUFF

40	Potatoes, sugar beets, alfalfa, alfalfa	257	296	279
21	Potatoes, sugar beets (manure)	195	224	279
	Difference in favor of alfalfa	62	72	0
44	Potatoes, oats, alfalfa, alfalfa	286	264	270
25	Potatoes, oats (manure)	224	233	287
	Difference in favor of alfalfa	62	31	−17
60	Potatoes, oats, sugar beets, alfalfa, alfalfa, alfalfa	273	295	329
31	Potatoes, oats (manure), sugar beets	223	244	312
	Difference in favor of alfalfa	50	51	17

[1] For the period 1916–18 only.

The yields of potatoes at Belle Fourche, as a result of the manurial treatment, was in excess of the yields from rotations including alfalfa in all instances except in the 44 and 25 comparison, when the differences for all the periods are slightly in favor of alfalfa. At the Huntley station increases in the yields of potatoes resulting from 2 or 3 years of alfalfa as compared with farm manure have been neither consistent nor pronounced with the exception of the 60 and 31 comparison. A comparison of these 2 rotations by 7-year periods reveals a uniformly substantial difference in favor of the rotations including alfalfa. Only three pairs of rotations are available at the Scotts Bluff station. In all 7-year periods but 2, and they occur in the last period, alfalfa shows some superiority over stable manure in influencing the yields of potatoes. The superiority of alfalfa at this station is minimized, however, when the mean increases for the three 7-year periods are computed. Beginning with the 1912–18 period the mean increases are 58, 51, and 0 bushels per acre. This would indicate that the manurial treatment is developing a more favorable soil condition than is alfalfa. The trend of the potato yields in the different individual rotations tends to support this hypothesis.

EFFECT OF MANURE ON YIELDS OF OATS

In table 7 are recorded the yields of oats to show the influence of applications of farm manure on this crop in 14 comparisons at the 3 stations. In view of the fact that oats was not considered a major crop at the time these rotations were inaugurated, the manure was in no case applied directly preceding the oat crop, as had occurred in several instances with potatoes and sugar beets. One or more crops always intervened, and in rotation 61 five seasons elapsed between the time of application of manure and that when the oats were grown.

TABLE 7.—*Effect of manure on yields of oats (bushels per acre) at the Belle Fourche, Huntley, and Scotts Bluff Field Stations by 7-year periods, 1912–32*

BELLE FOURCHE

Rotation no.	Crop sequence	1912–18	1919–25	1926–32
		Bushels	*Bushels*	*Bushels*
23	Oats (manure), sugar beets	70	56	62
22	Oats, sugar beets	71	52	57
	Difference in favor of manure	−1	4	5
25	Oats (manure), potatoes	65	66	69
24	Oats, potatoes	71	60	57
	Difference in favor of manure	−6	6	12
31	Oats (manure), sugar beets, potatoes	77	62	64
30	Oats, sugar beets, potatoes	69	50	53
	Difference in favor of manure	8	12	11
35	Oats (manure), potatoes, sugar beets	----------	50	49
34	Oats, potatoes, sugar beets	----------	49	50
	Difference in favor of manure	----------	1	−1
61	Oats (manure), sugar beets, alfalfa, alfalfa, alfalfa, potatoes	74	49	69
60	Oats, sugar beets, alfalfa, alfalfa, alfalfa, potatoes	67	52	65
	Difference in favor of manure	7	−3	4

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TABLE 7.—*Effect of manure on yields of oats (bushels per acre) at the Belle Fourche, Huntley, and Scotts Bluff Field Stations by 7-year periods, 1912–32*—Continued

HUNTLEY

Rotation no.	Crop sequence	1912–18	1919–25	1926–32
		Bushels	*Bushels*	*Bushels*
23	Oats (manure), sugar beets	79	78	85
22	Oats, sugar beets	89	79	77
	Difference in favor of manure	−10	−1	8
25	Oats (manure), potatoes	92	84	96
24	Oats, potatoes	85	71	65
	Difference in favor of manure	7	13	31
31	Oats (manure), sugar beets, potatoes	76	72	66
30	Oats, sugar beets, potatoes	70	64	57
	Difference in favor of manure	6	8	9
35	Oats (manure), potatoes, sugar beets	[1] 88	86	74
34	Oats, potatoes, sugar beets	[1] 95	81	68
	Difference in favor of manure	−7	5	6
61	Oats (manure), sugar beets, alfalfa, alfalfa, alfalfa, potatoes	97	92	112
60	Oats, sugar beets, alfalfa, alfalfa, alfalfa, potatoes	91	94	110
	Difference in favor of manure	6	−2	2

SCOTTS BLUFF

23	Oats (manure), sugar beets	68	62	62
22	Oats, sugar beets	65	43	30
	Difference in favor of manure	3	19	32
25	Oats (manure), potatoes	65	61	56
24	Oats, potatoes	66	44	25
	Difference in favor of manure	−1	17	31
31	Oats (manure), sugar beets, potatoes	77	70	58
30	Oats, sugar beets, potatoes	66	52	29
	Difference in favor of manure	11	18	29
61	Oats (manure), sugar beets, alfalfa, alfalfa, alfalfa, potatoes	73	79	80
60	Oats, sugar beets, alfalfa, alfalfa, alfalfa, potatoes	70	74	71
	Difference in favor of manure	3	5	9

[1] For the period 1916–18 only.

A comparison of the differences between manured and untreated rotations at the Belle Fourche station for the three periods indicates that applications of manure did not increase the yields of oats appreciably except in the oats-potato rotations 24 and 25 and in 3-year rotations 30 and 31. The results for the three 7-year periods show that there has been a definite tendency for the oat yields to decrease in rotation 24, whereas there was a slight but progressive increase in the oat yields in rotation 25. Applications of farm manure influenced the yields of oats favorably in rotation 31 as compared with similar rotation 30, which was untreated. Significant differences in the yields of oats did not occur during any of the periods in 2-year rotations 22

and 23, 3-year rotations 34 and 35, nor in the 6-year rotations 60 and 61. At the Huntley station the manurial treatment did not materially increase the yields of oats, except in the case of oat-potato rotations 24 and 25 where the differences are significant. The results with oats at Scotts Bluff indicate that applications of stable manure over a long period may be expected to increase yields in crop sequences similar to those recorded here with the exception of 6-year alfalfa rotations comparable to 60 and 61. For the first 7-year period in the nonalfalfa rotations, in none of the comparisons was the difference in yields greatly in favor of the manure. The superiority of the manured rotations was definitely greater for the second 7-year period; and for the last 7-year period, 1926–32, the mean increase for the first 3 rotations was 31 bushels to the acre and within the narrow range of 29 to 32 bushels.

EFFECT OF ALFALFA ON YIELDS OF OATS

The extent to which alfalfa influenced the yields of oats at the 3 stations is recorded in table 8, which includes 19 comparisons. It will be noted that in rotation 42 the oat crop immediately follows alfalfa; whereas in other cases there is an intervening cultivated crop such as potatoes, which is usually considered a better farm practice.

TABLE 8.—*Effect of alfalfa on yields of oats (bushels per acre) at the Belle Fourche, Huntley, and Scotts Bluff Field Stations by 7-year periods, 1912–32*

BELLE FOURCHE

Rotation no.	Crop sequence	1912–18	1919–25	1926–32
		Bushels	*Bushels*	*Bushels*
42	Oats, sugar beets, alfalfa, alfalfa	48	39	44
22	Oats, sugar beets	71	52	57
	Difference in favor of alfalfa	−23	−13	−13
44	Oats, alfalfa, alfalfa, potatoes	83	51	72
24	Oats, potatoes	71	60	57
	Difference in favor of alfalfa	12	−9	15
48	Oats, alfalfa, alfalfa, spring wheat	82	52	59
28	Oats, spring wheat	35	23	23
	Difference in favor of alfalfa	47	29	36
60	Oats, sugar beets, alfalfa, alfalfa, alfalfa, potatoes	67	52	65
30	Oats, sugar beets, potatoes	69	50	53
	Difference in favor of alfalfa	−2	2	12
61	Oats (manure), sugar beets, alfalfa, alfalfa, alfalfa, potatoes	74	49	69
31	Oats (manure), sugar beets, potatoes	77	62	64
	Difference in favor of alfalfa	−3	−13	5
62	Oats, sugar beets, alfalfa, alfalfa, alfalfa, corn	62	39	51
32	Oats, sugar beets, corn	57	34	39
	Difference in favor of alfalfa	5	5	12
64	Oats, alfalfa, alfalfa, alfalfa, potatoes, sugar beets	----------	48	55
34	Oats, potatoes, sugar beets	----------	49	50
	Difference in favor of alfalfa	----------	−1	5

TABLE 8.—*Effect of alfalfa on yields of oats (bushels per acre) at the Belle Fourche, Huntley, and Scotts Bluff Field Stations by 7-year periods, 1912–32*—Continued

HUNTLEY

Rotation no.	Crop sequence	1912–18	1919–25	1926–32
		Bushels	*Bushels*	*Bushels*
42	Oats, sugar beets, alfalfa, alfalfa	86	90	101
22	Oats, sugar beets	89	79	77
	Difference in favor of alfalfa	−3	11	24
44	Oats, alfalfa, alfalfa, potatoes	78	86	97
24	Oats, potatoes	85	71	65
	Difference in favor of alfalfa	−7	15	32
46	Oats, alfalfa, alfalfa, sugar beets	[1] 87	90	99
22	Oats, sugar beets	[1] 92	79	77
	Difference in favor of alfalfa	−5	11	22
60	Oats, sugar beets, alfalfa, alfalfa, alfalfa, potatoes	91	94	110
30	Oats, sugar beets, potatoes	70	64	57
	Difference in favor of alfalfa	21	30	53
61	Oats (manure), sugar beets, alfalfa, alfalfa, alfalfa, potatoes	97	92	112
31	Oats (manure), sugar beets, potatoes	76	72	66
	Difference in favor of alfalfa	21	20	46
64	Oats, alfalfa, alfalfa, alfalfa, potatoes, sugar beets	[1] 87	89	89
34	Oats, potatoes, sugar beets	[1] 95	81	68
	Difference in favor of alfalfa	−8	8	21

SCOTTS BLUFF

42	Oats, sugar beets, alfalfa, alfalfa	73	66	68
22	Oats, sugar beets	65	43	30
	Difference in favor of alfalfa	8	23	38
44	Oats, alfalfa, alfalfa, potatoes	75	70	69
24	Oats, potatoes	66	44	25
	Difference in favor of alfalfa	9	26	44
48	Oats, alfalfa, alfalfa, spring wheat	66	69	60
28	Oats, spring wheat	55	33	21
	Difference in favor of alfalfa	11	36	39
60	Oats, sugar beets, alfalfa, alfalfa, alfalfa, potatoes	70	74	71
30	Oats, sugar beets, potatoes	66	52	29
	Difference in favor of alfalfa	4	22	42
61	Oats (manure), sugar beets, alfalfa, alfalfa, alfalfa, potatoes	73	79	80
31	Oats (manure), sugar beets, potatoes	77	70	58
	Difference in favor of alfalfa	−4	9	22
62	Oats, sugar beets, alfalfa, alfalfa, alfalfa, corn	59	69	68
32	Oats, sugar beets, corn	56	38	24
	Difference in favor of alfalfa	3	31	44

[1] For the period 1916–18 only.

Under the conditions at the Belle Fourche station the most consistently unsatisfactory results occurred where the oat crop immediately followed alfalfa in rotation 42 as compared with rotation 22.

The largest difference in favor of alfalfa for the three 7-year periods was in the oats-spring wheat rotations 28 and 48. It is worthy of note that in all 7 pairs, with the exception of the 22 and 42 rotations, the differences for the last 7-year period, even if slight in some instances, are in favor of the rotations having alfalfa. Including alfalfa in the cropping program at the Huntley station has had a uniformly beneficial effect on the yields of oats, as is evidenced by a comparison of the three 7-year periods. Even where the oat crop immediately follows alfalfa in rotation 42 as compared with rotation 22 the differences increased progressively for the 3 periods. The results at Huntley indicate further that the better yields of oats are to be expected in rotations like no. 60 having 3 years of alfalfa. That the oat yields in rotation 60 have tended to increase, whereas those harvested from rotation 30 have progressively decreased is shown by a comparison of the three 7-year periods. Alfalfa included in five of the rotations at the Scotts Bluff station had a definitely stimulating influence on the yields of oats in all rotations, particularly during the last two 7-year periods. At this station there have been no increased yields of oats as a result of 3 years of alfalfa as compared with 2 years.

EFFECT OF MANURE AS COMPARED WITH ALFALFA ON YIELDS OF OATS

The extent that alfalfa influenced the yields of oats as compared with applications of farm manure is shown in 12 comparisons in table 9. In all cases where the manurial treatment was applied one or more crops intervened between the treatment and the oat crop. On the other hand, in one instance (rotation 42) the oat crop immediately followed alfalfa, while in others a cultivated crop intervened between the alfalfa and the oat crops. In rotation 64 following alfalfa two cultivated crops were grown—potatoes and sugar beets.

TABLE 9.—*Effect of manure as compared with alfalfa on yields of oats (bushels per acre) at the Belle Fourche, Huntley, and Scotts Bluff Field Stations by 7-year periods, 1912–32*

BELLE FOURCHE

Rotation no.	Crop sequence	1912–18	1919–25	1926–32
		Bushels	*Bushels*	*Bushels*
42	Oats, sugar beets, alfalfa, alfalfa	43	39	44
23	Oats (manure), sugar beets	70	56	62
	Difference in favor of alfalfa	−22	−17	−18
44	Oats, alfalfa, alfalfa, potatoes	83	51	72
25	Oats (manure), potatoes	65	66	69
	Difference in favor of alfalfa	18	−15	3
60	Oats, sugar beets, alfalfa, alfalfa, alfalfa, potatoes	67	52	65
31	Oats (manure), sugar beets, potatoes	77	62	64
	Difference in favor of alfalfa	−10	−10	1
64	Oats, alfalfa, alfalfa, alfalfa, potatoes, sugar beets	----------	48	55
35	Oats (manure), potatoes, sugar beets	----------	50	49
	Difference in favor of alfalfa	----------	−2	6

TABLE 9.—*Effect of manure as compared with alfalfa on yields of oats (bushels per acre) at the Belle Fourche, Huntley, and Scotts Bluff Field Stations by 7-year periods, 1912–32*—Continued

HUNTLEY

Rotation no.	Crop sequence	1912–18	1919–25	1926–32
		Bushels	*Bushels*	*Bushels*
42	Oats, sugar beets, alfalfa, alfalfa	86	90	101
23	Oats (manure), sugar beets	79	78	85
	Difference in favor of alfalfa	7	12	16
44	Oats, alfalfa, alfalfa, potatoes	78	86	97
25	Oats (manure), potatoes	92	84	96
	Difference in favor of alfalfa	−14	2	1
46	Oats, alfalfa, alfalfa, sugar beets	[1] 87	90	99
23	Oats (manure), sugar beets	[1] 78	78	85
	Difference in favor of alfalfa	9	12	14
60	Oats, sugar beets, alfalfa, alfalfa, alfalfa, potatoes	91	94	110
31	Oats (manure), sugar beets, potatoes	76	72	66
	Difference in favor of alfalfa	15	22	44
64	Oats, alfalfa, alfalfa, alfalfa, potatoes, sugar beets	[1] 87	89	89
35	Oats (manure), potatoes, sugar beets	[1] 88	86	74
	Difference in favor of alfalfa	−1	3	15

SCOTTS BLUFF

42	Oats, sugar beets, alfalfa, alfalfa	73	66	68
23	Oats (manure), sugar beets	68	62	62
	Difference in favor of alfalfa	5	4	6
44	Oats, alfalfa, alfalfa, potatoes	75	70	69
25	Oats (manure), potatoes	65	61	56
	Difference in favor of alfalfa	10	9	13
60	Oats, sugar beets, alfalfa, alfalfa, alfalfa, potatoes	70	74	71
31	Oats (manure), sugar beets, potatoes	77	70	58
	Difference in favor of alfalfa	−7	4	13

[1] 1916–18 only.

The results obtained thus far at the Belle Fourche station indicate that applications of manure increased the yields of oats more than the alfalfa for all 3 periods in the 42 and 23 comparison. When the results from the other three pairs of rotations are considered, the differences are not consistent or of a magnitude to be considered significant. At the Huntley station the differences in the oat yields for all three 7-year periods in the 42 and 23, the 46 and 23, and the 60 and 31 comparisons are more consistent and of a magnitude to indicate that alfalfa in such crop sequences is distinctly superior to farm manure. Negative results have occurred where oats and potatoes have been grown in the 44 and 25 rotations. For the last 7-year period the difference of 15 bushels per acre in oat yields in the 64 and 35 rotations indicates that the cumulative beneficial effect of alfalfa is in excess of that from stable manure. In all but 1 instance the differences in oat yields at the Scotts Bluff station for the three 7-year periods are in favor of alfalfa. However, these differences are not great.

RESULTS OF THE DIFFERENT TREATMENTS SUMMARIZED

While generally the beneficial effects on subsequent crop yields resulting from including a leguminous crop in the cropping program have been too long and too well recognized to require emphasis, the results of these investigations have disclosed that there is grave danger of overestimating the value of a leguminous crop such as alfalfa in stimulating crop yields as compared with applications of farm manure. The inadequacy of the information with respect to the merits of these two soil-improvement agencies has resulted in the too general assumption that the inclusion of alfalfa in the cropping program is, in a large measure at least, a satisfactory substitute for applications of farm manure. From these results it is apparent that there is need for more precise information regarding the comparative merits of the two agencies under varying soil conditions, as well as the frequency of their appearance and location in the cropping program. Furthermore, the application of manure is a laborious task, and, partly because of this fact, there is a tendency among many farmers to allow the accumulation of this valuable farm asset to waste with the expectation that their crop yields may be maintained satisfactorily by means of alfalfa. These investigations indicate that such an assumption is not always well founded, particularly when sugar beets are involved.

The effects of manure and of alfalfa on the yields of sugar beets, potatoes, and oats have been recorded in the foregoing tables by 7-year periods for the 21 years. By this method of presentation it is possible to show the actual mean yields harvested in the different rotations for the three periods and the yield trends, that is, the extent that yields of sugar beets, potatoes, and oats have been diminished or increased as a result of the use of manure or the inclusion of alfalfa in the rotations. The following tables and discussions are devoted to a summary of the results obtained from the different rotations and treatments in which the mean yields, the differences in yields, and the standard error are computed. These condensed tables have been compiled for the purpose of ascertaining and comparing the magnitude of the differences and its significance as expressed by the standard error. The yields from each of the 3 stations are given in each table in order to afford a direct comparison of results obtained at the 3 localities. In order to afford an opportunity to observe the extent to which the different treatments have influenced the yields of the 3 crops at the 3 stations, the combined mean differences for similar rotations have been computed.

In considering the summary of the results recorded in the following tables it should be recognized that the second and particularly the last 7-year period more accurately reflect the differences which may be attributed to the rotational treatments. It has become increasingly apparent that 7 years is too brief a period to afford reliable conclusions even for rotations as short as those having a 2-year cycle. When those having a 6-year cycle are involved it is obvious that but 3 complete cycles will have been completed at the end of the third 7-year period. In such instances it is evident that but little significance can be placed on the yields and differences recorded for the first two periods. While it is apparent that the mean yields for the combined 21 years completely mask yield trends, yet this method of presentation affords an opportunity to compare directly the 21-year mean

yields for the different treatments and the reliability of the results by determining the standard error at the 3 locations.

The extent that yields of sugar beets have been influenced at the 3 stations by applications of stable manure is given in table 10. The increases in yields have ranged from a minimum of 2.6 tons at the Belle Fourche station in the 61 and 60 6-year rotation, which includes 3 years of alfalfa, to a maximum of 7.8 tons at the Scotts Bluff in the 23 and 22 pair, which are 2-year rotations with oats the preceding crop. Not only are the increases in yields of beets appreciably due to applications of stable manure, but when the yield differences are compared with the standard error they are found to be significant in every instance.

TABLE 10.—*The influence of stable manure on the mean acre yields of sugar beets at the Belle Fourche, Huntley, and Scotts Bluff Field Stations for the period 1912–32*

Rotation no.	Crop sequence	Belle Fourche		Huntley		Scotts Bluff	
		Acre yield	Standard error	Acre yield	Standard error	Acre yield	Standard error
		Tons		*Tons*		*Tons*	
21	Sugar beets (manure), potatoes	15.7	----	16.0	----	16.8	----
20	Sugar beets, potatoes	12.0	----	11.7	----	10.8	----
	Difference in favor of manure	3.7	±0.59	4.3	±0.76	6.0	±0.75
23	Sugar beets, oats (manure)	14.4	----	14.2	----	18.2	----
22	Sugar beets, oats	10.7	----	8.5	----	10.4	----
	Difference in favor of manure	3.7	±.61	5.7	±1.14	7.8	±.64
31	Sugar beets, potatoes, oats (manure)	12.0	----	13.9	----	18.0	----
30	Sugar beets, potatoes, oats	7.6	----	8.0	----	10.7	----
	Difference in favor of manure	4.4	±.53	5.9	±.78	7.3	±.54
35	Sugar beets, oats (manure), potatoes	----	----	[1] 14.5	----	----	----
34	Sugar beets, oats, potatoes	----	----	[1] 10.1	----	----	----
	Difference in favor of manure	----	----	4.4	±1.12	----	----
61	Sugar beets, alfalfa (3 years), potatoes, oats (manure)	13.2	----	15.9	----	19.2	----
60	Sugar beets, alfalfa (3 years), potatoes, oats	10.6	----	12.7	----	14.5	----
	Difference in favor of manure	2.6	±.57	3.2	±.73	4.7	±.27
	Mean difference of rotations 21 and 20, 23 and 22, 31 and 30, and 61 and 60	3.6	----	4.8	----	6.4	----

[1] For the period 1916–32 only.

It will be observed from the results at the 3 stations that in every instance the increases have been the largest at the Scotts Bluff station, which has the lightest soil. At the Belle Fourche station, which has a heavy gumbo soil, the increases in yields attributed to the manurial treatment are consistently the lowest. The soil conditions at the Huntley station are intermediate between the other two, as are the differences. The mean differences in favor of manure for the 4 similar rotations are: Belle Fourche 3.6, Huntley 4.8, and Scotts Bluff 6.4 tons per acre, or an increase of about 55 percent for the Scotts Bluff station.

There are 7 pairs of rotations which indicate the effect of alfalfa on the yields of sugar beets. The results from 4 of these pairs have been accumulated over the entire 21-year period for all 3 stations. The mean yields and differences for the 3 stations are given in table 11.

TABLE 11.—*The influence of alfalfa on the mean acre yields of sugar beets at the Belle Fourche, Huntley, and Scotts Bluff Field Stations for the period 1912–32*

Rotation no.	Crop sequence	Belle Fourche		Huntley		Scotts Bluff	
		Acre yield	Standard error	Acre yield	Standard error	Acre yield	Standard error
		Tons		*Tons*		*Tons*	
40	Sugar beets, alfalfa (2 years), potatoes	11.8		11.4		17.0	
20	Sugar beets, potatoes	12.0		11.7		10.8	
	Difference in favor of alfalfa	−.2	±0.39	−.3	±0.69	6.2	±0.64
42	Sugar beets, alfalfa (2 years), oats	9.1		9.7		15.7	
22	Sugar beets, oats	10.7		8.5		10.4	
	Difference in favor of alfalfa	−1.6	±.46	1.2	±.74	5.3	±.77
46	Sugar beets, oats, alfalfa (2 years)	[1] 7.8		[1] 9.3			
22	Sugar beets, oats	[1] 11.2		[1] 8.5			
	Difference in favor of alfalfa	−3.4	±.57	.8	±.73		
60	Sugar beets, alfalfa (3 years), potatoes, oats	10.6		12.7		14.5	
30	Sugar beets, potatoes, oats	7.6		8.0		10.7	
	Difference in favor of alfalfa	3.0	±.43	4.7	±.55	3.8	±.60
61	Sugar beets, alfalfa (3 years), potatoes, oats (manure)	13.2		15.9		19.2	
31	Sugar beets, potatoes, oats (manure)	12.0		13.9		18.0	
	Difference in favor of alfalfa	1.2	±.68	2.0	±.67	1.2	±.51
62	Sugar beets, alfalfa (3 years), corn, oats	8.9				14.1	
32	Sugar beets, oats, corn	6.6				10.6	
	Difference in favor of alfalfa	2.3	±.40			3.5	±.53
64	Sugar beets, oats, alfalfa (3 years), potatoes	[1] 12.2		[1] 12.0			
34	Sugar beets, oats, potatoes	[1] 13.2		[1] 10.1			
	Difference in favor of alfalfa	−1.0	±.50	1.9	±.71		
	Mean difference of rotations 40 and 20, 42 and 22, 60 and 30, and 61 and 31	.6		1.9		4.1	

[1] For the period 1916–32 only.

The mean yields of the 4 rotations for the 3 stations show that only 0.6 of a ton increase may be attributed to alfalfa at Belle Fourche, 1.9 tons at Huntley, and 4.1 tons at the Scotts Bluff station. These mean results indicate that on the average alfalfa has not materially stimulated sugar-beet yields on the heavy gumbo soil at the Belle Fourche station, but at Huntley some increase is noted, while at the Scotts Bluff station definitely favorable results have been obtained. It should be noted that at Belle Fourche negative differences have been obtained in the yield of beets from each of the 4-year rotations having 2 years of alfalfa. On the other hand, when the differences are computed in the 6-year combinations having 3 years of alfalfa there is an increase in the yields in 3 cases out of the 4.

Somewhat comparable results have been obtained at the Huntley station. There were slight increases in the differences in 2 out of 3 instances in the rotations having 2 years of alfalfa, but in none of the combinations are the differences significant. At this station a definite increase in the yields of beets is apparent when rotation 60 is compared with rotation 30. However, in the other 2 combinations 3 years of alfalfa have had a less favorable influence on the yields of beets.

The yield differences from each of the combinations at the Scotts Bluff station in favor of alfalfa range from a minimum of 1.2 to a maximum of 6.2 tons of beets to the acre. Furthermore, contrary to the results obtained at the other 2 stations, at this station 2 years of alfalfa have materially stimulated the yields of beets, there being a mean difference of 5.8 tons per acre for these 2 rotations. The mean difference for the 2 pairs having 3 years of alfalfa and where the manurial treatment is not involved is only 3.7 tons, or a difference in favor of rotations having only 2 years of alfalfa of 2.1 tons of beets to the acre. From these results it might appear that 2 years were superior to 3 years of alfalfa. However, 2 crops come between the alfalfa and sugar beets in rotations 60 and 61, whereas there is only 1 crop in 4-year rotations 40 and 42.

For all 3 stations the second largest mean yield of beets, 14.6 tons per acre, is from rotation 31, to which farm manure was applied every third year to the beet crop. Rotation 61 is similar as to major crops and also as to manurial treatment, but 3 years of alfalfa is included between the beet and potato crops. The mean yield of rotation 61 for the 3 stations is 16.1 tons per acre, the largest yield of any of the 14 rotations listed in this table and 1.5 tons per acre in excess of the companion rotation 31. These results indicate that increases in beet yields may be expected even in rotations which include applications of stable manure by having alfalfa in the cropping program.

Table 12 affords comparison of the yields obtained from the 3 crops during the 21-year period from applications of farm manure as compared with alfalfa in otherwise similar crops and crop sequences. This table presents available evidence from 13 different combinations. In only 1, rotation 21 as compared with rotation 40 at Scotts Bluff, has alfalfa been as effective as the manure in increasing the yields of beets. When the mean differences for all the combinations for each of the 3 stations are considered it will be found that as compared with alfalfa the manurial treatment has increased the yields of beets 3.5 tons at Belle Fourche, 3.4 tons at Huntley, and 1.9 tons per acre at Scotts Bluff. However, in the 31 and 60 comparison it should be recognized that the manure is applied immediately preceding the beets in rotation 31, whereas 2 crops, potatoes and oats, come between the alfalfa and the beets in rotation 60. In this latter rotation it seems probable that the productivity of the soil may have been somewhat exhausted by the time the beets were grown.

The increase in the yields of beets as a result of the manurial treatment as compared with alfalfa ranged from a minimum difference of −0.2 ton from rotations 21 and 40 at Scotts Bluff to a maximum difference of 8.3 tons per acre from rotations 23 and 46 at Belle Fourche. The differences from both the Belle Fourche and Huntley stations indicate definitely the superiority of applications of farm manure as compared with alfalfa, particularly in the rotations having only 2 years of alfalfa. The manurial treatment at these two stations was superior to alfalfa even in the 31 and 60 and the 35 and 64 combinations, which had 3 years of alfalfa. It is possible to observe the effect on the yields of beets as compared with alfalfa in only 3 instances at the Scotts Bluff station. In 2 out of the 3 combinations the manurial treatment has proved to be superior to alfalfa, the yield increases

being 2.5 to 3.5 tons per acre for these 2 pairs of rotations. It is apparent that applications of the manure have been distinctly superior to alfalfa in stimulating the yields of sugar beets in these crop sequences at the three stations. From the 3 similar rotations increases are shown ranging from 12 percent at Scotts Bluff, 30 percent at Huntley, and 33 percent at Belle Fourche.

TABLE 12.—*The influence of stable manure as compared with alfalfa on the mean acre yields of sugar beets at the Belle Fourche, Huntley, and Scotts Bluff Field Stations for the period 1912–32*

Rotation no.	Crop sequence	Belle Fourche		Huntley		Scotts Bluff	
		Acre yield	Standard error	Acre yield	Standard error	Acre yield	Standard error
		Tons		*Tons*		*Tons*	
21	Sugar beets (manure), potatoes	15.7		16.0		16.8	
40	Sugar beets, alfalfa (2 years), potatoes	11.8		11.4		17.0	
	Difference in favor of manure	3.9	±0.63	4.6	±1.03	−.2	±0.78
23	Sugar beets, oats (manure)	14.4		14.2		18.2	
42	Sugar beets, alfalfa (2 years), oats	9.1		9.7		15.7	
	Difference in favor of manure	5.3	±.84	4.5	±1.14	2.5	±.64
23	Sugar beets, oats (manure)	[1] 16.1		[1] 14.1			
46	Sugar beets, oats, alfalfa, alfalfa	[1] 7.8		[1] 9.3			
	Difference in favor of manure	8.3	±.68	4.8	±1.37		
31	Sugar beets, potatoes, oats (manure)	12.0		13.9		18.0	
60	Sugar beets, alfalfa (3 years), potatoes, oats	10.6		12.7		14.5	
	Difference in favor of manure	1.4	±.42	1.2	±.73	3.5	±.56
35	Sugar beets, oats (manure), potatoes	[1] 15.5		[1] 14.5			
64	Sugar beets, oats, alfalfa (3 years), potatoes	[1] 12.2		[1] 12.0			
	Difference in favor of manure	3.3	±.52	2.5	±.84		
	Mean difference of rotations 21 and 40, 23 and 42, and 31 and 60	3.5		3.4		1.9	

[1] For the period 1916–32 only.

The extent to which applications of farm manure influenced the yields of potatoes is shown in 14 different instances in table 13. The mean increase which may be attributed to the manurial treatment for all the combinations at Belle Fourche is 32 bushels, at Huntley 50 bushels, and at Scotts Bluff 67 bushels per acre.

The yield increases of potatoes as a result of the manurial treatment ranged from −4 bushels per acre at Belle Fourche in the 61 and 60 rotations to a maximum of 129 bushels per acre at Huntley in the 25 and 24 rotations. In all but two instances significant increases in yields were obtained as a result of this treatment. For the 3 stations farm manure applied to rotation 61 resulted in the lowest increase, the mean being 14 bushels per acre. In this rotation 4 years elapse between the applications of manure and the potato crop. It is reasonable to assume that the favorable effects of the application of 12 tons of manure would not be so apparent after 4 years as would be the case if only one crop intervened or the application were made just prior to the potato crop.

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TABLE 13.—*The influence of stable manure on the mean acre yields of potatoes at the Belle Fourche, Huntley, and Scotts Bluff Field Stations for the period 1912–32*

Rotation no.	Crop sequence	Belle Fourche		Huntley		Scotts Bluff	
		Acre yield	Standard error	Acre yield	Standard error	Acre yield	Standard error
		Bushels		*Bushels*		*Bushels*	
21	Potatoes, sugar beets (manure)	162		243		233	
20	Potatoes, sugar beets	103		196		150	
	Difference in favor of manure	59	±10.4	47	±15.2	83	±16.8
25	Potatoes, oats (manure)	149		313		248	
24	Potatoes, oats	123		184		155	
	Difference in favor of manure	26	±5.4	129	±12.1	93	±12.8
31	Potatoes, oats (manure), sugar beets	165		176		260	
30	Potatoes, oats, sugar beets	117		176		187	
	Difference in favor of manure	48	±7.0	0	±8.4	73	±13.5
35	Potatoes, sugar beets, oats (manure)	185		298			
34	Potatoes, sugar beets, oats	149		247			
	Difference in favor of manure	36	±10.6	51	±15.8		
61	Potatoes, oats (manure), sugar beets, alfalfa (3 years)	129		315		319	
60	Potatoes, oats, sugar beets, alfalfa (3 years)	133		290		299	
	Difference in favor of manure	−4	±5.6	25	±12.7	20	±6.0
	Mean difference of rotations 21 and 20, 25 and 24, 31 and 30, and 61 and 60	32		50		67	

The extent to which alfalfa influenced the yields of potatoes is indicated in table 14. There are 14 instances where the differences may be observed for the 21 years. The mean differences for similar rotations show that alfalfa has increased the yields of potatoes at Belle Fourche 12 bushels, at Huntley 85 bushels, and at Scotts Bluff 104 bushels per acre.

TABLE 14.—*The influence of alfalfa on the mean acre yields of potatoes at the Belle Fourche, Huntley, and Scotts Bluff Field Stations for the period 1912–32*

Rotation no.	Crop sequence	Belle Fourche		Huntley		Scotts Bluff	
		Acre yield	Standard error	Acre yield	Standard error	Acre yield	Standard error
		Bushels		*Bushels*		*Bushels*	
40	Potatoes, sugar beets, alfalfa (2 years)	131		267		277	
20	Potatoes, sugar beets	103		196		150	
	Difference in favor of alfalfa	28	±7.5	71	±16.2	127	±14.9
44	Potatoes, oats, alfalfa (2 years)	162		202		273	
24	Potatoes, oats	123		184		155	
	Difference in favor of alfalfa	39	±7.7	18	±18.2	118	±12.9
60	Potatoes, oats, sugar beets, alfalfa (3 years)	133		290		299	
30	Potatoes, oats, sugar beets	117		176		187	
	Difference in favor of alfalfa	16	±6.8	114	±12.0	112	±12.8
61	Potatoes, oats (manure), sugar beets, alfalfa (3 years)	129		315		319	
31	Potatoes, oats (manure), sugar beets	165		176		260	
	Difference in favor of alfalfa	−36	±10.3	139	±14.2	59	±11.2
64	Potatoes, sugar beets, oats, alfalfa (3 years)	121		308			
34	Potatoes, sugar beets, oats	149		247			
	Difference in favor of alfalfa	−28	±8.5	61	±21.9		
	Mean difference of rotations 40 and 20, 44 and 24, 60 and 30, and 61 and 31	12		85		104	

The maximum increase which may be attributed to the alfalfa of 139 bushels per acre occurred at Huntley in the 61 and 31 rotations, both of which had applications of farm manure. At Belle Fourche, involving the same pair, there is a —36-bushel decrease. In none of the five combinations did the increase exceed the 39 bushels per acre at Belle Fourche. On the other hand, at Huntley substantial increases are apparent in each of the 5 comparisons except in that involving the 44 and 24 pair, where the increase was only 18 bushels per acre, with a standard error of ±18.2. At Scotts Bluff substantial increases in the yields of potatoes occurred, ranging from a minimum of 59 bushels to a maximum of 127 bushels per acre.

In 11 different instances at the three stations an opportunity is afforded to compare the effect of alfalfa with applications of farm manure on the yields of potatoes. The mean differences in favor of alfalfa from the same rotations at all 3 locations indicate that alfalfa as compared with manure has influenced yields of potatoes to the extent of —17 bushels at Belle Fourche, 9 bushels at Huntley, and 36 bushels per acre at Scotts Bluff. The summary of the mean yields and the differences are given in table 15.

TABLE 15.—*The influence of alfalfa as compared with stable manure on the mean acre yields of potatoes at the Belle Fourche, Huntley, and Scotts Bluff Field Stations for the period 1912–32*

Rotation no.	Crop sequence	Belle Fourche		Huntley		Scotts Bluff	
		Acre yield	Standard error	Acre yield	Standard error	Acre yield	Standard error
		Bushels		*Bushels*		*Bushels*	
40	Potatoes, sugar beets, alfalfa (3 years)	131		267		277	
21	Potatoes, sugar beets (manure)	162		243		233	
	Difference in favor of alfalfa	−31	±7.5	24	±14.1	44	±13.3
44	Potatoes, oats, alfalfa (2 years)	162		202		273	
25	Potatoes, oats (manure)	149		313		248	
	Difference in favor of alfalfa	13	±9.2	−111	±15.8	25	±11.5
60	Potatoes, oats, sugar beets, alfalfa (3 years)	133		290		299	
31	Potatoes, oats (manure), sugar beets	165		176		260	
	Difference in favor of alfalfa	−32	±9.4	114	±14.2	39	±11.3
64	Potatoes, sugar beets, oats, alfalfa (3 years)	[1] 121		[1] 308			
35	Potatoes, sugar beets, oats (manure)	[1] 185		[1] 298			
	Difference in favor of alfalfa	−64	±12.8	10	±18.2		
	Mean difference of rotations 40 and 21, 44 and 25, and 60 and 31	−17		9		36	

[1] For the period 1916–32 only.

In only 1 instance out of the 4 did alfalfa prove to be as effective with potatoes as applications of manure at Belle Fourche, and this occurred in the 44 and 25 pair where the increase totaled only 13 bushels per acre, accompanied with a high standard error. In the other three instances the differences are definitely in favor of the manurial treatment. At the Huntley station the mean differences are in favor of alfalfa with the exception of the 44 and 25 comparison. The lowest mean yield at this station, 202 bushels per acre, is from rotation 44 having oats and 2 years of alfalfa as the companion crops.

In a large measure the relatively low yields of potatoes harvested from rotation 44 as compared with the yields from the other alfalfa rotations is believed chiefly due to the fact that the soil where rotation 44 is located is less favorable for potato production. When the manure was applied to 2-year rotation 25 with oats as the companion crop, and the manure applied following the oat crop, 313 bushels of potatoes have been harvested, the highest mean yield recorded at this station, and 111 bushels per acre in excess of the yield from rotation 44. At Huntley only one observation is possible where an intervening crop was grown between the manurial application and the potatoes, and that is rotation 31 with a mean yield of 176 bushels per acre. This rotation may be compared with no. 35 having the same crops but in slightly different sequence, the manure being aplied directly preceding the potato crop, and a mean yield produced of 298 bushels, or 122 bushels per acre in excess of rotation 31. Yield increases which may be attributed to alfalfa as compared with manure at the Scotts Bluff station are moderate but consistent, the maximum being 44 and the minimum 25 bushels per acre.

In planning these rotation experiments the chief objective was to arrange the crop sequences and the time of applying the manure so that the two major cash crops, sugar beets, and potatoes, would be in a position to benefit most from the crop sequences and treatments. Oats were selected from among the cereals to be included in the rotation, partly for the purpose of observing the effect of a cereal on subsequent crop yields of both potatoes and sugar beets. At the same time it was recognized that the feed requirements of many farm enterprises are such that one of the cereals could be incorporated advantageously in the cropping program and that information concerning the effect the different treatments and crop sequences would have on oat yields would be highly useful in conducting the farming operations efficiently.

The mean acre yields of oats together with the standard error are given in table 16 as this crop appears in the different crop sequences where manure is applied as compared with those not so treated. The mean yield increases from comparable rotations for the three stations are: Belle Fourche 4 bushels, Huntley 6 bushels, and Scotts Bluff 15 bushels per acre.

Yield differences are recorded in 14 instances, and yield increases are positive in 13 of the 14. The differences range from 0 in the 35 and 34 pair at Belle Fourche to 19 bushels per acre in the 31 and 30 comparison at Scotts Bluff. At the Belle Fourche station the maximum increase of 11 bushels per acre occurs in the 31 and 30 comparison. The other 4 differences range from 0 to 4 bushels per acre. At this station applications of farm manure did not increase the yields of oats materially, although yield increases occurred in 4 of the 5 instances. When compared with the standard error they appear to be significant. At the Huntley station the maximum increase was 17 bushels and the minimum —1 bushel per acre, and in the 2 other rotations increases of only 2 bushels per acre occurred. In only 2 instances of the 5 are there significant differences when compared with the standard error. The yield differences recorded for the Scotts Bluff station indicate that in all instances the manurial treatment had a favorable influence on the yields of oats, ranging from 5

to 19 bushels per acre; although in the 61 and 60 comparison, both of which had 3 years of alfalfa, there was only a 5-bushel increase.

TABLE 16.—*The influence of stable manure on the mean acre yields of oats at the Belle Fourche, Huntley, and Scotts Bluff Field Stations for the period 1912–32*

Rotation no.	Crop sequence	Belle Fourche		Huntley		Scotts Bluff	
		Acre yield	Standard error	Acre yield	Standard error	Acre yield	Standard error
		Bushels		*Bushels*		*Bushels*	
23	Oats (manure), sugar beets	63		81		64	
22	Oats, sugar beets	60		82		46	
	Difference in favor of manure	3	±1.4	−1	±3.2	18	±3.3
25	Oats (manure), potatoes	67		91		61	
24	Oats, potatoes	63		74		45	
	Difference in favor of manure	4	±2.5	17	±3.3	16	±4.2
31	Oats (manure), sugar beets, potatoes	68		71		68	
30	Oats, sugar beets, potatoes	57		64		49	
	Difference in favor of manure	11	±1.6	7	±2.4	19	±2.5
35	Oats (manure), potatoes, sugar beets	[1] 50		[1] 83			
34	Oats, potatoes, sugar beets	[1] 50		[1] 81			
	Difference in favor of manure	0	±2.0	2	±2.8		
61	Oats (manure), sugar beets, alfalfa (3 years), potatoes	64		100		77	
60	Oats, sugar beets, alfalfa (3 years), potatoes	61		98		72	
	Difference in favor of manure	3	±2.0	2	±3.1	5	±1.5
	Mean difference of rotations 23 and 22, 25 and 24, 31 and 30, and 61 and 60	4		6		15	

[1] For the period 1916–32 only.

At the three stations there was an opportunity to observe the influence alfalfa exerted on oat yields in 19 different instances. There are 4 identical combinations at the 3 stations with a mean yield difference from similar rotations of −3 bushels at Belle Fourche, 22 bushels at Huntley, and 20 bushels per acre at Scotts Bluff. The results are recorded in table 17.

The differences for all stations varied from −16 bushels in the 42 and 22 pair at Belle Fourche to 34 bushels per acre in the 60 and 30 pair at Huntley. When the results from the 3 stations are considered separately it is apparent that at the Belle Fourche station there is a definitely significant increase in the yield of oats in only one instance. This is revealed by a comparison of the yields from rotation 48 with those from rotation 28. Consideration should be given to the fact that rotation 28 has a 2-year cycle and the companion crop of oats is spring wheat. This has proved to be an undesirable sequence and has notably depressed the yields of both wheat and oats, chiefly because of weeds. The mean yield of oats in this rotation is 27 bushels per acre, the lowest of any in the series listed in this table. Consequently, it is believed that the weeds in this rotation have been the chief cause of the lower oat yields rather than the gradual exhaustion of the productivity of the soil. Eliminating the 48 and 28 combination and taking a mean of the differences of the remaining 6 combinations, it is found that alfalfa has neither depressed nor increased

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oat yields for a 21-year period under the heavy soil conditions existing at this station.

TABLE 17.—*The influence of alfalfa on the mean acre yields of oats at the Belle Fourche, Huntley, and Scotts Bluff Field Stations for the period 1912–32*

Rotation no.	Crop sequence	Belle Fourche		Huntley		Scotts Bluff	
		Acre yield	Standard error	Acre yield	Standard error	Acre yield	Standard error
		Bushels		*Bushels*		*Bushels*	
42	Oats, sugar beets, alfalfa (2 years)	44		92		69	
22	Oats, sugar beets	60		82		46	
	Difference in favor of alfalfa	−16	±2.6	10	±3.7	23	±4.6
44	Oats, alfalfa (2 years), potatoes	69		87		71	
24	Oats, potatoes	63		74		45	
	Difference in favor of alfalfa	6	±4.2	13	±4.4	26	±4.3
46	Oats, alfalfa (2 years), sugar beets			[1] 92			
22	Oats, sugar beets			[1] 83			
	Difference in favor of alfalfa			9	±5.3		
48	Oats, alfalfa (2 years), spring wheat	64				65	
28	Oats, spring wheat	27				36	
	Difference in favor of alfalfa	37	±5.5			29	±3.7
60	Oats, sugar beets, alfalfa (3 years), potatoes	61		98		72	
30	Oats, sugar beets, potatoes	57		64		49	
	Difference in favor of alfalfa	4	±2.6	34	±4.9	23	±4.5
61	Oats (manure), sugar beets, alfalfa (3 years), potatoes	64		100		77	
31	Oats (manure), sugar beets, potatoes	68		71		68	
	Difference in favor of alfalfa	−4	±3.1	29	±5.4	9	±4.0
62	Oats, sugar beets, alfalfa (3 years), corn	51				65	
32	Oats, sugar beets, corn	43				39	
	Difference in favor of alfalfa	8	±2.3			26	±4.9
64	Oats, alfalfa (3 years), potatoes, sugar beets	[1] 52		[1] 88			
34	Oats, potatoes, sugar beets	[1] 50		[1] 81			
	Difference in favor of alfalfa	2	±3.7	7	±4.4		
	Mean difference of rotations 42 and 22, 44 and 24, 60 and 30, and 61 and 31	−3		22		20	

[1] For the period 1916–32 only.

These results indicate that at the Huntley station the inclusion of alfalfa in the cropping program consistently increased oat yields, although in 3 of the 6 rotation comparisons the differences are small and not particularly significant when compared with the standard error.

In all but one instance the differences are substantial and significant in favor of alfalfa at the Scotts Bluff station. Alfalfa did not materially stimulate the yields of oats in rotation 61 as compared with rotation 31. The mean increase in the yield of oats for the other 5 comparisons is 25 bushels per acre, with a relatively low standard error in every instance.

By selecting comparable rotations, those having in them an application of farm manure and the others including alfalfa, it is possible to observe and compare directly the extent that these treatments

have influenced the yields of oats. There are 5 pairs of rotations affording such comparisons, and for the 3 stations 12 differences are available. Table 18 records these results.

TABLE 18.—*The influence of alfalfa as compared with stable manure on the mean acre yields of oats at the Belle Fourche, Huntley, and Scotts Bluff Field Stations for the period 1912–32*

Rotation no.	Crop sequence	Belle Fourche		Huntley		Scotts Bluff	
		Acre yield	Standard error	Acre yield	Standard error	Acre yield	Standard error
		Bushels		*Bushels*		*Bushels*	
42	Oats, sugar beets, alfalfa (2 years)	44		92		69	
23	Oats (manure), sugar beets	63		81		64	
	Difference in favor of alfalfa	−19	±2.8	11	±2.9	5	±2.7
44	Oats, alfalfa (2 years), potatoes	69		87		71	
25	Oats (manure), potatoes	67		91		61	
	Difference in favor of alfalfa	2	±5.0	−4	±3.1	10	±2.5
46	Oats, alfalfa (2 years), sugar beets			[1] 92			
23	Oats (manure), sugar beets			[1] 80			
	Difference in favor of alfalfa			12	±4.2		
60	Oats, sugar beets, alfalfa (3 years), potatoes	61		98		72	
31	Oats (manure), sugar beets, potatoes	68		71		68	
	Difference in favor of alfalfa	−7	±2.8	27	±4.3	4	±3.1
64	Oats, alfalfa (3 years), potatoes, sugar beets	[1] 52		[1] 88			
35	Oats (manure), potatoes, sugar beets	[1] 50		[1] 83			
	Difference in favor of alfalfa	2	±2.6	5	±3.3		
	Mean difference of rotations 42 and 23, 44 and 25, and 60 and 31	−8		11		6	

[1] For the period 1916–32 only.

When the mean differences for the same rotations at the three stations are computed it is found that at Belle Fourche the inclusion of alfalfa in the cropping program, as compared with the manurial treatment, influenced oat yields to the extent of −8 bushels, at Huntley 11 bushels, and at Scotts Bluff 6 bushels per acre. In only 4 instances of the 12 were there significant yield increases which could be attributed to the alfalfa as compared with the manured rotations. At Belle Fourche negative differences occurred in 2 instances, and in those cases where positive increases occurred there is only a 2-bushel difference. The most favorable results as far as alfalfa is concerned occurred at Huntley where significant yield increases are to be noted in 3 of the 5 instances where comparisons are possible. At Scotts Bluff, apparently, alfalfa, as compared with manure, did not stimulate the yields of oats materially, the maximum being only 10 bushels per acre in the 44 and 25 comparison.

INFLUENCE ON SUGAR BEET YIELDS OF PASTURING OTHER CROPS IN ROTATIONS

In the series of rotations herein reported, which include those receiving applications of farm manure as compared with alfalfa, the results indicate that, as far as the yields of sugar beets are concerned,

the manurial treatment is distinctly more effective than alfalfa in maintaining and improving yields, particularly at the Belle Fourche and Huntley stations. When the beet yields in rotations having 2 years of alfalfa are compared with those where alfalfa has been grown 3 years, the favorable effects on the yield of beets are more pronounced. At all three stations, however, the manurial treatment still is distinctly superior to alfalfa, even in the rotations having 3 years of alfalfa, although the position of alfalfa and the manurial treatment in relation to sugar beets should be recognized.

Where alfalfa or sweetclover is grown chiefly for the purpose of stimulating crop yields, some available evidence indicates that if these crops are pastured 1 or more years the yields following such a practice are materially in excess of those obtained where such crops are harvested for hay. At the time these rotation experiments were inaugurated information as to the possibilities of such a procedure was not available. Only a few rotations including pastured crops were incorporated in the series of experiments, and, unfortunately, these were not directly comparable, particularly as to sequences, with any of the other rotations. In 1926 several additional rotations were added to the series, including sweetclover or alfalfa to be pastured. Comparable rotations, unpastured, are a part of this series. Results are available for only 7 years; consequently, not too much credence should be given to the results obtained for this relatively short period.

Table 19 shows the extent that sugar beet yields have been influenced by pasturing in 2 pairs of rotations, 1 pair at Belle Fourche and the other pair at Huntley. All four rotations include 3 years of alfalfa. The comparison available at the Belle Fourche station is between rotations 71 and 60. During 5 of the 6 years of the cycle the crops were the same, but for the sixth year 1 rotation included oats and the other beets. The sequences varied slightly, but it is believed that the differences in yields of beets which occurred may be attributed in a large measure to pasturing both corn and alfalfa. The comparison at Huntley is between rotations 67 and 60. In both rotations the beet crop is 2 years removed from alfalfa. The condensed results are recorded in table 19, which includes the mean yields for the three 7-year periods, the mean yield for the 17 years at Belle Fourche, the mean yield for the 21 years at Huntley, and the standard error.

TABLE 19.—*The influence of pasturing other crops on mean acre yields of sugar beets (tons) at the Belle Fourche and the Huntley Field Stations, 1916–32 and 1912–32*

BELLE FOURCHE

Rotation no.	Crop sequence	1916–18	1919–25	1926–32	17-year mean	Standard error
		Tons	*Tons*	*Tons*	*Tons*	
71	Sugar beets, oats, alfalfa, alfalfa, alfalfa (pastured), corn (harvested with lambs)	[1] 12.0	14.9	13.9	13.9	
60	Sugar beets, alfalfa, alfalfa, alfalfa, potatoes, oats	[1] 11.2	11.3	10.5	10.9	
	Difference in favor of pasturing	.8	3.6	3.4	3.0	±0.26

[1] For 3-year period only. Other figures are for 7-year periods.

TABLE 19.—*The influence of pasturing other crops on mean acre yields of sugar beets (tons) at the Belle Fourche and the Huntley Field Stations, 1916–32 and 1912–32*—Continued

HUNTLEY

Rotation no.	Crop sequence	1912–18	1919–25	1926–32	21-year mean	Standard error
		Tons	*Tons*	*Tons*	*Tons*	
67	Sugar beets, alfalfa, alfalfa, alfalfa (pastured with hogs), corn (harvested with hogs), flax	13.9	16.2	17.1	15.7	
60	Sugar beets, alfalfa, alfalfa, alfalfa, potatoes, oats	10.5	14.0	13.6	12.7	
	Difference in favor of pasturing	3.4	2.2	3.5	3.0	±0.54

At Belle Fourche the beet yields from rotation 71 were consistently higher than those harvested from rotation 60 and definitely so for the last two 7-year periods. The mean increase for the 17-year period is 3.0 tons of beets to the acre, or 28 percent, which it is believed may be attributed chiefly to pasturing the alfalfa the third year and harvesting the corn crop with lambs. At the Huntley station the third year of alfalfa and the following corn crop were both harvested with hogs. Here again substantial yield increases occurred when rotations 60 and 67 are compared, ranging from a minimum of 2.2 tons to a maximum of 3.5 tons, and a mean increase for the 21-year period of 3.0 tons per acre, or approximately 24 percent.

It is recognized that the foregoing results indicating the extent that sugar beet yields may be influenced favorably by pasturing are not conclusive. However, they do conform with results obtained with certain other crops when alfalfa was pastured (*1*, *2*) and emphasize the need for further information with respect to the possibilities of the practice.

YIELD DIFFERENCES EXPRESSED AS PERCENTAGES

The mean yields of sugar beets, potatoes, and oats in the various rotations which received applications of farm manure and those which include alfalfa are recorded in the foregoing tables. These results have been compared with similar rotations not so treated and the differences in the yields determined. While these data permit a study of the yields from different cropping systems and the extent that yields have been influenced in tons and bushels, direct comparisons cannot be made by this method. However, such a comparison is made in table 20, in which the yield differences are expressed in percentages and include the results from all three stations. By this method it is possible to present, in terms of percentages, the influence of the manure on the yields of the 3 crops as compared with untreated rotations as well as with those which have 2 and 3 years of alfalfa. Percentage figures are given indicating the extent that yields are influenced when alfalfa is grown for 2 and 3 years as compared with similar rotations not including alfalfa. It is possible also to make 2 yield comparisons with the alfalfa-manure rotation with 1 untreated and another having alfalfa only. The various percentage differences are given in table 20.

TABLE 20.—*Yield increases or decreases expressed in percentages, following applications of stable manure and including alfalfa in the crop rotations at the Belle Fourche, Huntley, and Scotts Bluff Field Stations, 1912–32*

Crops and field stations where grown	Stable manure compared with—			Alfalfa compared with untreated—		Alfalfa 3 years and manure compared with—	
	Untreated	Alfalfa 2 years	Alfalfa 3 years	Alfalfa 2 years	Alfalfa 3 years	Untreated	Alfalfa alone
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Sugar beets:							
Belle Fourche	38	60	21	−15	15	74	21
Huntley	53	46	15	6	36	99	15
Scotts Bluff	66	8	24	54	35	79	24
Potatoes:							
Belle Fourche	32	6	39	30	−2	10	9
Huntley	24	19	−21	23	42	79	9
Scotts Bluff	51	−13	−15	80	60	71	7
Oats:							
Belle Fourche	10	15	4	18	8	12	5
Huntley	9	−7	−17	14	30	56	2
Scotts Bluff	38	−11	−6	62	56	57	7

Yield increases of sugar beets as a result of applications of farm manure were substantial in every instance except at Scotts Bluff when compared with 2 years of alfalfa, where the increase is only 8 percent. At the other 2 stations the manurial treatment was distinctly superior to 2 years of alfalfa, showing an increase of 60 percent at Belle Fourche and 46 percent at Huntley. Apparently 3 years of alfalfa had a more favorable effect on the yields of beets than 2 years of alfalfa, but even when these rotations are compared with the manured rotations the latter treatment proves to be distinctly superior in its effect on beet yields. Two years of alfalfa appear to have depressed beet yields at Belle Fourche and not appreciably increased them at Huntley. On the other hand, at Scotts Bluff there is an indicated increase of 54 percent from 2 years of alfalfa. There is a 15-percent increase as a result of 3 years of alfalfa at Belle Fourche and a 36 and 35-percent increase, respectively, at the other 2 stations. The largest percentage increases of beet yields occurred at all 3 stations from a rotation including both alfalfa and manure as compared with those from the corresponding rotation untreated, the range being from 74 percent at Belle Fourche to 99 percent at Huntley. Farm manure in rotation 61 resulted in yield increases of beets ranging from 15 to 24 percent as compared with rotation 60.

In considering the percentage differences with potatoes, the yield increases are less than with sugar beets and also somewhat less consistent. As compared with the untreated rotations manure definitely stimulated potato yields. When the manurial treatment is compared with 2 and 3 years of alfalfa at Belle Fourche the percentage figures are in favor of manure; the results are not consistent at Huntley; while at Scotts Bluff the potato yields were better following alfalfa. Rotations including alfalfa as compared with those untreated returned the largest increases with one exception. By comparing the alfalfa-untreated percentages with those given in the two manure-alfalfa columns it becomes apparent that, with the exception of Belle Fourche, alfalfa had a more favorable influence on the yields of potatoes than applications of stable manure. Grouping the results from the three stations, the most favorable increase in the yield of

potatoes occurred when the alfalfa-manure rotation is compared with the untreated one. These percentages further indicate that when manure is applied to rotation 61 as compared with 60, material increases in the yield of potatoes are not to be expected.

The manurial treatment applied to these rotations increased the yields of oats only slightly at Belle Fourche and Huntley, but it increased the yield materially, 38 percent, at Scotts Bluff. On the other hand, alfalfa appears to have had a more favorable influence on yields of oats both at Huntley and Scotts Bluff, with the manurial treatment slightly superior at Belle Fourche. When the 2- and 3-year alfalfa rotations are compared with the rotations not including this crop, the percentages from all 3 stations are in favor of alfalfa. As occurred with both sugar beets and potatoes, oat yields responded most favorably to the alfalfa-manure treatment when compared with a rotation untreated. Percentage differences in favor of the manure in an alfalfa rotation, although slight, are consistent.

In the foregoing pages, which have been confined to the discussion of the influence of farm manure and alfalfa on the yields of sugar beets, potatoes, and oats, consideration has been given only to the difference in yields as influenced by these two treatments under varying conditions. Notably at Scotts Bluff the quality of the potatoes was adversely affected by scab in the shorter rotations not including alfalfa but receiving applications of manure. On the other hand, even in the shorter rotations, such as 40 and 44, but which include alfalfa, the potatoes were notably free from the scab disease.

In all instances applications of farm manure stimulated the yields of sugar beets. However, there is evidence to indicate that as sugar-beet yields are increased their sucrose percentages decrease somewhat.[3] At Scotts Bluff, where extremely heavy applications of farm manure were made on land to be planted to sugar beets, the sucrose content of the beets was unfavorably influenced as compared with lighter applications of manure and the lower yields of beets resulting therefrom. At present there is no evidence to indicate that the same result would not occur where beet yields were materially increased by including alfalfa in the cropping program.

SUMMARY

The 21-year results of experiments with farm manure and alfalfa on subsequent crop yields were obtained at the Belle Fourche (S. Dak.), Huntley (Mont.), and Scotts Bluff (Nebr.) Field Stations. These stations are located in the northern part of the Great Plains. The crops involved are sugar beets, potatoes, and oats.

The climate is semiarid and does not differ materially at the three locations. The soils at the three stations range from a heavy clay or gumbo at Belle Fourche to a friable, fine sandy loam at Scotts Bluff. The soil conditions at Huntley are about intermediate.

The rotations from which results are recorded were selected from a relatively extensive series inaugurated in 1912 as a part of the investigational program at the three stations.

There are nine pairs of rotations which include alfalfa as compared with those having the same crops and sequences but without alfalfa.

[3] NUCKOLS, S. B. THE RESIDUAL EFFECTS OF MANURIAL TREATMENT UPON THE QUALITY OF SUGAR BEETS. [In manuscript.]

Five pairs of rotations received applications of farm manure as compared with similar simple rotations. In six instances the manurial treatment is compared with similar rotations but including alfalfa.

In presenting the data for the 21 years, the mean yields by 7-year periods are given first. In each instance mean yields from sugar beets, potatoes, or oats are compared, and the increase or decrease which may be attributed to the treatments is determined.

At all three stations applications of farm manure increased the yields of sugar beets materially in every instance, the maximum increase amounting to 11.2 tons per acre.

The increased yields of sugar beets as a result of including alfalfa in the cropping program were not consistent. At Scotts Bluff increased yields of beets as a result of alfalfa occurred consistently. At the other two stations 2 years of alfalfa have increased the yields of beets in only a few instances.

The effect of applications of farm manure as compared with alfalfa on the yields of beets is given in table 3. In every instance during the last 7-year period the manurial treatment proved superior to alfalfa, the yield increases ranging from a minimum of 1.5 to a maximum of 11.1 tons per acre.

Applications of farm manure resulted in increasing the yields of potatoes at all three stations, although the increases were not so pronounced as in the case of sugar beets. The manurial treatment has not increased the yields of potatoes in an alfalfa rotation.

When the potato yields from similar rotations are compared with the one including alfalfa and the others not having this crop, it is apparent that alfalfa favorably influenced the yields of potatoes at Scotts Bluff and at Huntley. Consistent results were not obtained at Belle Fourche where the soil conditions are less favorable for potato production.

At Belle Fourche in 3 out of 4 rotations larger yields of potatoes resulted from the manurial treatment than occurred following alfalfa. The results at the other two stations were less consistent, although it is evident that the manurial treatment sustained potato yields better than alfalfa.

During the first two 7-year periods applications of farm manure did not increase the yields of oats materially in a large majority of instances at the 3 stations. Increases in the yields of oats which may be attributed to manure occurred at the 3 locations for the last 7-year period in all but 1 instance.

The inclusion of alfalfa in the cropping program stimulated the yields of oats in every instance at Huntley and Scotts Bluff and in all but one instance at Belle Fourche during the last 7-year period. Less consistent results occurred for the earlier periods.

The merits of farm manure and alfalfa are compared. At Belle Fourche the manurial treatment developed the best results in a majority of instances. On the other hand, at Huntley and Scotts Bluff alfalfa has produced the best results. The results of the different treatments are summarized for the 21-year period and the standard error is computed.

Significant increases in the yields of sugar beets attributed to applications of farm manure occurred in every instance, ranging from a mean of 3.6 tons at Belle Fourche to a maximum of 6.4 tons per acre at Scotts Bluff. Yield increases of beets in the alfalfa rotations,

compared with those not having alfalfa, ranged from a mean of 0.6 ton at Belle Fourche to a maximum of 4.1 tons per acre at Scotts Bluff. The mean superiority of the manured rotations as compared with those having alfalfa amounted to 3.5 tons at Belle Fourche, 3.4 tons at Huntley, and 1.9 tons per acre at Scotts Bluff.

Applications of farm manure resulted in increases in the yield of potatoes in most instances, the mean increases at the different stations ranging from 50 bushels at Belle Fourche to 67 bushels per acre at Scotts Bluff. It was found that alfalfa definitely stimulated potato yields at Huntley and Scotts Bluff but not consistently at Belle Fourche. When the effectiveness of both manure and alfalfa are compared in similar rotations, the manurial treatment appears to have been slightly superior at Belle Fourche, whereas at Scotts Bluff alfalfa produced somewhat better results.

Significant mean increases in the yields of oats as a result of the manurial treatment did not occur at either Belle Fourche or Huntley. However, the application of manure resulted in a material increase in the yields of oats in the three rotations not having alfalfa at Scotts Bluff. When oat yields from alfalfa rotations are compared with those not including that crop, it is found that alfalfa definitely stimulated oat yields at Huntley, whereas the results from the different rotations at Belle Fourche were not consistent. When oat yields from manured rotations are compared with those from rotations including alfalfa, the mean of the differences indicates that the manurial treatment was somewhat superior at Belle Fourche, whereas at Huntley and Scotts Bluff slightly better yields resulted from including alfalfa in the rotation.

In a number of instances the results obtained with sugar beets at Belle Fourche and Huntley indicate that alfalfa did not materially stimulate yields. Two comparisons are available as to the effect of pasturing other crops on the yields of sugar beets as compared with similar rotations not so treated. The results indicate that pasturing materially stimulates the yields of beets.

To afford a more direct comparison of the effect of the different treatments on the yields of sugar beets, potatoes, and oats, table 20 is included which expresses the yield differences in percentages.

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SELENIUM OCCURRENCE IN CERTAIN SOILS IN THE UNITED STATES WITH A DISCUSSION OF RELATED TOPICS

BY

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INTRODUCTION

For many years the existence of a disease of animals, apparently peculiar to certain portions of South Dakota and adjacent areas, has been recognized and described under the name of alkali disease. Apparently the first written mention of it is found in a statistical report on sickness and mortality in the Army of the United States by Madison (*15*),[1] dated September 1857, but not published until 1860. In this report Dr. Madison calls attention to a "very fatal disease" which manifested itself in August 1856 among the cavalry horses at Fort Randall in the then Nebraska Territory. He recognized the disease as new and gave a very satisfactory description of its symptoms. He also correctly ascribed the origin of the trouble to the pasturage. A study of this area is outlined in this bulletin. In later years the disease was supposed to be caused by the water of the area, which is very saline and quite capable of producing physiological disturbances. Because of the frequent loss and still more frequent illness of cattle, this supposed source of the trouble was investigated at the South Dakota Agricultural Experiment Station (*13, 14*), and the harmlessness of the water in this particular respect was established.

Numerous investigations on range poisons and on related topics have been published which bear on the general subject, but since they are not closely pertinent to the present purpose they will not be cited.

[1] Italic numbers in parentheses refer to Literature Cited, p. 46.

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The next step of major importance resulted from the work of Kurt W. Franke, station chemist of the South Dakota station. In 1928 Franke began a series of investigations which definitely determined that the disease in question is produced by consumption of grain and other vegetation grown upon definite soil areas. He was able also in a general way to show the extent of the areas in which this variety of toxic vegetation is normally produced. For the most part Franke's extensive work has not been published but a number of his papers have appeared (*5, 6, 7, 8, 9*).

As a result of a conference between Franke and Henry G. Knight, Chief of the Bureau of Chemistry and Soils, in March 1931, a cooperative study of the problem was begun, which involved work in the Bureaus of Home Economics, Animal Industry, and Plant Industry, as well as in the Bureau of Chemistry and Soils. Samples of toxic grain were furnished by Dr. Franke. Active work began about May 1, 1931.

A very considerable mass of evidence has been accumulated along several lines. It is not the purpose to present the results here except so far as they become essential to the subject under discussion.

On May 14, 1931, at a meeting of the interbureau committee, Dr. Munsell, of the Bureau of Home Economics, reported that symptoms in rats produced by feeding compounds of fluorine, lithium, and oxalic acid were different from those resulting when grain from alkali-disease areas was fed. In the ensuing discussion Knight suggested that selenium be looked for. As a result, W. O. Robinson was furnished on May 25 a sample of toxic wheat with the request that he determine the presence or absence of selenium. No positive methods for the detection of selenium in plant materials, particularly when the quantity was small, were then available. Acting upon the assumption that the selenium, were it present, might be expected to behave in a general way as does sulphur, he eventually analyzed the wheat by the method he describes (*17*). By this method he was able to show that selenium was present in the wheat to the extent of from 10 to 12 parts per million. In July and August 1931 a reconnaissance survey of the area known to be affected by the alkali disease was conducted by Franke, Rice, Johnson, and Schoening (*9*). Among the important findings of this survey were: The general area affected is more extensive than had been supposed; it is in general coextensive with the soils developed on the Pierre shale, and there is a wide variation in the intensity of the toxicity of the vegetation not only geographically but apparently also from season to season.

After the survey was completed, T. D. Rice, of the Soil Survey, collected a number of samples of soils which he sent to Washington. In these samples Robinson (*17*) determined the presence of selenium. Working with artificially selenized soils and sand cultures, Annie Hurd-Karrer, of the Bureau of Plant Industry, was able to produce seleniferous vegetation which was used by E. M. Nelson and also by Hazel E. Munsell to produce toxic effects in rats (*16*).

During 1932 and the early part of 1933 relatively little progress was made upon the soil phases of the project though marked progress was made in other lines. Particularly important is the contribution of Hurd-Karrer (*10, 11*) in demonstrating the inhibiting effect of increasing the sulphur content of the soil, and of nutrient solutions used in sand and water cultures, upon the absorption of selenium by plants.

Also important was the demonstration by Hazel Munsell and Grace DeVaney that the same disease symptoms were produced in white rats by inorganic selenium salts as by seleniferous grain. Rice also made a collection of soil and shale samples in which Robinson demonstrated the presence of selenium and with these examinations as well as with examinations of numerous samples of varied source Robinson began the development of the series of methods which were published in 1934 (*18*).

A specially fruitful result followed from a conference on November 16, 1932, between J. A. Hill, of the Wyoming Agricultural Experiment Station; W. W. Burr, of the Nebraska Agricultural Experiment Station; K. F. Kellerman, of the Bureau of Plant Industry; and Henry G. Knight, of the Bureau of Chemistry and Soils. At this conference it was brought out that Pierre shale existed as a soil parent material in both Wyoming and Nebraska and that toxic areas might be expected to exist in both States. In consequence of the work thus initiated, Beath (*1, 2*) and his associates were able to demonstrate the presence of selenium in vegetation grown on soils from a variety of shales and to relate the toxicity of many plants so grown to their selenium content. On July 21, 1933, an interbureau committee took up with the Secretary of Agriculture the need for a special grant of funds to conduct surveys and other investigations in an effort to definitely determine the areas injuriously affected by the presence of selenium in the soils. This was followed by a presidential order of September 5, 1933, authorizing the Secretary of Agriculture to set aside $35,000 for the prosecution of this work. The allotment was made September 19, 1933. The report which follows is a summary of the work accomplished under this grant so far as it concerns the soil areas and closely related topics.

PRELIMINARY SURVEY

Acting upon the authority granted, a preliminary survey was undertaken by T. D. Rice, K. W. Franke, and the writer. During a portion of the survey the party was accompanied by R. L. Piemeisel and Daniel R. Ready. The purpose was to ascertain if possible a method by which areas not likely to be affected could be eliminated from consideration and to determine whether any topographical, botanical, or other consideration could be used as a guide in the location of seleniferous areas. Since it had been shown that known affected areas were all located upon soils derived from Pierre shales, but that apparently certain of such soils are not toxic, it was hoped that certain plants might serve as indicators, either by their presence or absence, or that contours or other soil conformations might aid. No indications based upon plant distribution were detected by Mr. Piemeisel nor did any topographical indications seem useful.

Samples of both soil and vegetation were taken from varied sources and shale samples were secured at widely different points. These were sent to Washington and examined for their selenium content. Some of the results are detailed in a series of tables. No selenium content in exact quantitative terms is given for the samples of vegetation since at the time there was no reliable rapid method of analysis.

It will be noted that the selenium content of the vegetation is, in these tables, represented by symbols. The method used in making the determinations is that suggested by Schmidt (*19*). It consists in

digesting a sample of vegetation as in the Kjeldahl process for nitrogen, and adding to an aliquot of the clear digestate two drops of a saturated solution of codeine sulphate. In the presence of selenium a greenish-blue to blue color is developed. It was known that this test could not be used for soils since blue, or other colorations, are produced by a variety of substances, notably vanadium compounds. It was hoped, however, that it could be used for vegetation since the method is so admirably suited for routine work. An attempt was made to make it roughly quantitative by accurate determination of the depth of color produced by known selenium content of samples.

Table 1 gives the range of values shown by the symbols employed.

TABLE 1.—*The quantitative significance of the signs for selenium content by the codeine sulphate test*

Sign	Range	Sign	Range
	P. p. m.		*P. p. m.*
−	0- 5	2+	50–250
±	0–10	3+	150–360
+w	5–25	4+	300–700
+	15–70	5+	600+

The selenium content of samples of soil, shale, and vegetation in Nebraska and South Dakota is shown in table 2.

TABLE 2.—*Selenium content of samples of soil, shale, and vegetation in Nebraska and South Dakota*

Laboratory no.	Location	Material	Selenium in—	
			Soil or shale	Vegetation [1]
			P. p. m.	*P. p. m.*
B940	Boyd County, Nebr., T. 33 N., R. 10 W., sec. 12	Soil	1	
B941	do	Grasses		+
B942	do	Cane		+
B955	Boyd County, Nebr., T. 33 N., R. 9 W., sec. 8	Soil	2	
B943	do	Grasses		−
B956	Boyd County, Nebr., T. 33 N., R. 9 W., sec. 6	Gypsum	10	
B989	Boyd County, Nebr., T. 33 N., R. 10 W., sec. 16	Soil	.8	
B988	do	Foxtail		+
B866	Gregory County, S. Dak., T. 100 N., R. 72 W., sec. 21	Soil	2	
B867	do	Bluestem		+
B869	do	Soil	2.3	
B870	do	Russian thistle		2+
B898	Lyman County, S. Dak., T. 106 N., R. 73 W., sec. 27	Soil	.5	
B899	do	Grama grass		+
B918	Lyman County, S. Dak., T. 101 N., R. 73 W., sec. 23	Soil	2	
B887	do	Saltgrass		+
B394	Stanley County, S. Dak., T. 3. N., R. 31 E., sec. 28	Soil	4	
B998	do	Wheatgrass		3+
B1064	Haakon County, S. Dak., T. 1 N., R. 20 E., sec. 12	Soil	.6	
B1065	do	Wheatgrass		+
B1036	Jackson County, S. Dak., 5 miles north of Kadoka	Soil	.2	
B1036a	do	Wheatgrass		±
B1033	Jones County, S. Dak., ½ mile west of county line	Soil	1	
B1033a	do	Wheatgrass		±
B1056	Custer County, S. Dak., T. 3 S., R. 8 E., sec. 23	Soil	1	
B1057	do	Buffalo grass		±
B1060	do	Soil	5	
B1059	do	Cordgrass		+
B1047	Meade County, S. Dak., Alkali Creek	Soil	1.8	
B1048	do	Buffalo grass		+

[1] For significance of signs see table 1.

Since the season for field work in Nebraska and South Dakota was rapidly drawing to a close, two modes of attack were decided upon. One of these was an examination of the Pierre shale itself. The results of this effort are detailed in another part of this report (p. 7). The other mode of attack was to run transects across considerable areas of Pierre-derived soils at rather wide intervals both in areas known to be toxic and in areas in which no evidences of toxic conditions are obvious. This portion of the work was undertaken by T. D. Rice and F. W. Hayes of the Soil Survey. In general, the plan was to collect a sample of soil and of vegetation at intervals of a mile and to send these to Washington for examination. In addition to these transects they also conducted a close sampling of a number of fields from which toxic grain was known to come and of others believed to be free from toxicity. The samples sent to Washington were examined by Daniel Ready, A. Van Kleeck, Kenneth Williams, and H. C. Dudley who were aided in their work by the general advice of W. O. Robinson. Table 3 contains the results obtained on a sample transect and table 4 the results from a single field.

TABLE 3.—*Selenium content of soils and vegetation on a portion of a transect in Haakon County, S. Dak., on a line running from the Cheyenne River to the Bad River, traversing T. 8 N., south to T. 3 N., in Rs. 24 and 23 E; distance between samples being one-half mile*

Laboratory no.	Location	Material	Selenium in—	
			Soil or shale	Vegetation [1]
			P. p. m.	*P. p. m.*
B2730	T. 5 N., R. 24 E., sec. 5	Soil	0.4	
B2731	do	Grasses		±
B2732	T. 5 N., R. 24 E., sec. 6	Soil	.3	
B2733	do	Grasses		+
B2734	T. 5 N., R. 24 E., sec. 5	Soil	.3	
B2735	do	Grasses		±
B2736	do	Soil	.2	
B2737	do	Grasses		±
B2738	do	Soil	.5	
B2739	do	Grasses		+
B2740	T. 5 N., R. 24 E., sec. 4	Soil	.3	
B2741	do	Grasses		+
B2742	T. 5 N., R. 24 E., sec. 9	Soil	1.5	
B2743	do	Grasses		+
B2744	T. 5 N., R. 24 E., sec. 8	Soil	1	
B2745	do	Grasses		+
B2746	T 5 N., R. 24 E., sec. 9	Soil	1	
B2747	do	Grasses		+
B2748	T 5 N., R. 24 E., sec. 17	Soil	.7	
B2749	do	Grasses		±
B2750	T 5 N., R. 24 E., sec. 16	Soil	2	
B2751	do	Grasses		+
B2752	T 5 N., R. 24 E., sec. 17	Soil	2	
B2753	do	Grasses		+
B2754	T 5 N., R. 24 E., sec. 21	Soil	2	
B2755	do	Grasses		±
B2756	T 5 N., R. 24 E., sec. 20	Soil	.7	
B2757	do	Grasses		±

[1] For significance of signs see table 1.

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TABLE 4.—*Selenium content of soils and vegetation from pasture land of Joseph Micanek, sec. 1, T. 33 N., R. 10 W., Boyd County, Nebr.*

Laboratory no.	Field no.	Material	Selenium in—		Laboratory no.	Field no.	Material	Selenium in—	
			Soils or shales	Vegetation [1]				Soils or shales	Vegetation [1]
			P.p.m.	*P.p.m.*				*P.p.m.*	*P.p.m.*
B1267	M1	Soil	2		B1310	M16	Soil	2	
B1268	M1a	Wild aster		2+	B1311	M16a	Ragweed		+
B1269	M1b	Goldenrod		2+	B1312	M17	Soil	.5	
B1270	M2	Soil	2		B1313	M17a	Ragweed		+
B1271	M2a	Wild aster		3+	B1314	M18	Soil	2	
B1272	M2b	Goldenrod		+	B1315	M18a	Sand sage		2+
B1273	M3	Soil	1.3		B1316	M18b	Wild aster		3+
B1274	M3a	Wild aster		2+	B1317	M19	Soil	2	
B1275	M3b	Grama grass		+	B1318	M19a	Wild aster		4+
B1276	M4	Soil	2.3		B1319	M19b	Sand sage		+
B1277	M4a	Kuhnia		±	B1320	M20	Soil	2	
B1278	M4b	Wheatgrass		2+	B1321	M20a	Wild aster		+
B1279	M4c	Ragweed		−	B1322	M20b	Lambsquarters		+
B1280	M5	Soil	.1		B1323	M21	Soil	1.5	
B1281	M5a	Wild aster		+	B1324	M21a	Wild aster		2+
B1282	M5b	Wheatgrass		+	B1325	M21b	Pennyroyal		+
B1283	M6	Soil	.1		B1326	M22	Soil	1	
B1284	M6a	Ragweed		+	B1327	M22a	Wild aster		+
B1285	M7	Soil	2		B1328	M23	Soil	1.6	
B1286	M7a	Wild aster		2+	B1329	M23a	Wild aster		5+
B1287	M7b	Ragweed		+	B1330	M23b	Side-oats		±
B1288	M8	Soil	7		B1331	M24	Soil	[2]	
B1289	M8a	Wild aster		3+	B1332	M24a	Wild aster		±
B1290	M8b	Ragweed		+	B1333	M24b	Side-oats		±
B1291	M9	Soil	14		B1334	M25	Soil	.8	
B1292	M9a	Wild aster		6+	B1335	M25a	Wild aster		+
B1293	M9b	Ragweed		+	B1336	M25b	Side-oats		−
B1294	M10	Soil	2		B1337	M26	Soil	.7	
B1295	M10a	Wild aster		3+	B1338	M26a	Cordgrass		−
B1296	M11	Soil	3		B1339	M26b	Bluestem		±
B1297	M11a	Wild aster		3+	B1340	M27	Soil	.1	
B1298	M11b	Grama grass		+	B1341	M27a	Wild aster		−
B1299	M12	Soil	1.5		B1342	M27b	Side-oats		±
B1300	M12a	Wild aster		+	B1343	M28	Soil	.5	
B1301	M13	Soil	1		B1344	M28a	Wild aster		+
B1302	M13a	Cordgrass		+	B1345	M28b	Mixed grasses		+
B1303	M13b	Bluestem		+	B1346	M29	Soil	.8	
B1304	M14	Soil	9		B1347	M29a	Wild aster		3+
B1305	M14a	Wild aster		+	B1348	M29b	Verbena		+
B1306	M14b	Ragweed		+	B1349	M30	Soil	.2	
B1307	M15	Soil	2.5		B1350	M30a	Wild aster		+
B1308	M15a	Ragweed		+	B1351	M30b	Verbena		−
B1309	M15b	Grama grass		+					

[1] For significance of signs see table 1.
[2] Trace.

The results given in tables 2, 3, and 4, are typical of those derived from some 20 transects covering several hundred miles in SouthDakota and Nebraska, and of 10 areas, each of 160 acres or less, which were intensively sampled. Several facts are demonstrated by the mass of data assembled. The selenium occurs generally in all the areas of Pierre-derived soils, but its distribution is "spotty" in the extreme. The occurrence of selenium in the vegetation is also general wherever it is present in the soil. There is wide variation of quantity and there is no clearly defined relationship between the quantity found in the soil and that in plants. It became quite clear that the codeine sulphate method is not satisfactory and in all subsequent work the method developed by Van Kleeck (*18*) was used.

SELENIUM IN THE PIERRE SHALES

Since the preliminary survey (*9*) had shown a general coincidence of the areas known to be affected with the alkali disease with the areas of soil derived from Pierre shale as shown by the reconnaissance soil survey (*3*) made in 1909, it seemed probable that the scope of the investigation could be greatly narrowed were it possible to show that portions of this shale have no selenium content. This shale deposit is of enormous extent and outcrops in North Dakota, South Dakota, Nebraska, Montana, Wyoming, Colorado, New Mexico, and perhaps elsewhere. Also, it is made up of a very great number of separate layers of material of widely different composition. If these compose definite zones, it might be possible to trace these zones to definite areas of soil production.

This work was undertaken by Jerry E. Upp, geologist, of the University of Nebraska. He collected and sent to the laboratories in Washington about 500 samples representing the various strata occurring in the various recognized subdivisions of the Pierre shale which outcrop in Nebraska and South Dakota. These are grouped as zones A, B, C, D, E, and F. No portion of the A, or top zone, of the Pierre shale was recognized as the probable parent material of any of the soils in which the presence of selenium has been determined. Sections of this zone were, however, sent in from Brown and Keyapaha Counties, Nebr. All the other zones were represented. Also, it was found possible to sample the basal portion of the F zone and the top portion of the Niobrara chalk which immediately underlies the Pierre shale.

The examination of these samples revealed the presence of selenium in every case. The quantities found range from traces to upwards of 100 p. p. m. As a rule, the quantities found were less than 10 p. p. m. for the upper zones and upwards of 10 p. p. m. for the lower zones of the shale. It seems unnecessary to present all the analyses, but tables 5 and 6 present a portion of the Pierre profile. Table 5 is a portion of the C zone, and table 6 of the D zone. In table 7 are presented the selenium of the lower portion of zone F of the Pierre shale and of the upper portion of the Niobrara chalk. The presence of selenium in the Niobrara chalk vastly extends the area of possible soil contamination and this assumption is amply confirmed both in this laboratory and by Beath and his coworkers (*1*, *2*).

It will be observed that the shale strata vary widely in selenium content, and, even in the absence of any removal of selenium during the progress of weathering, it is to be expected that the derived soils would likewise vary. It is quite impossible to conceive of no removal of selenium during the process of weathering.

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TABLE 5.—*Selenium content of shale samples from NWSE sec. 11, T. 34 N., R. 13 W., left bank of Ponca Creek, south of Anoka, top to base, portion of zone C, Butte Township, Boyd County, Nebr.*

Laboratory no.	Field no.	Material	Thickness	Selenium
				P. p. m.
B3399	11.14c	Shale	2 feet	28
B3398	11. 14b	do	3 feet	29
B3397	11. 14a	do	3 feet	52
B3396	11. 13	Siltstone	1 inch	26
B3395	11. 12b	Ironstone and mudstone	4 feet	14
B3394	11. 12a	do	3 feet	4
B3393	11. 11	do	3 inches	8
B3392	11. 10e	Ironstone and shale	1 foot 6 inches	10
B3390	11. 10c	do	2 feet 6 inches	20
B3389	11. 10b	do	2 feet 6 inches	16
B3388	11. 10a	do	2 feet 6 inches	14
B3387	11. 9c	Shale	4 feet 6 inches	23
B3386	11. 9b	do	4 feet	14
B3385	11. 9a	do	4 feet	26
B3384	11. 7g	do	1 foot	16
B3383	11. 7f	do	2 feet	3
B3382	11. 7e	do	3 feet	3
B3381	11. 7d	do	3 feet	20
B3380	11. 7c	do	3 feet	14
B3379	11. 7b	do	3 feet	28
B3378	11. 7a	do	3 feet	26
B3377	11. 6	Ironstone and mudstone seam	1 foot 6 inches	10
B3376	11. 1–5e	Shale	4 feet	21
B3375	11. 1–5d	do	3 feet	23
B3374	11. 1–5c	do	3 feet	26
B3373	11. 1–5b	do	4 feet	24

TABLE 6.—*Selenium content of shale samples from sec. 30, T. 33 N., R. 11 W., top to base, portion of zone D, Bristow Township, Boyd County, Nebr.*

Laboratory no.	Field no.	Material	Thickness	Selenium
				P. p. m.
B3330T	9. 49	Shale, top	4 feet	22
B3330B	9. 49	Shale, base		20
B3329	9. 48	Bentonite and gypsum	1 inch	22
B3328	9. 47	Gypsum streak		5
B3328T	9. 47	Shale, top	6 feet 8 inches	32
B3328M	9. 47	Shale, middle		20
B3328B	9. 47	Shale, base		32
B3327	9. 46	Limestone and chalk	10 feet 1 inch	1. 5
B3326	9. 45	Bentonite	1–2 inches	9
B3325	9. 44	Shale	2 feet	8
B3324	9. 43	do	3 feet	5
B3322	9. 41	Bentonite	¼ inch	76
B3321	9. 40	Shale	2 feet	103
B3320	9. 39	Limestone	1 foot	12
B3319	9. 38	do	1 foot, 3 inches	46
B3318	9. 37	Shale	8–10 inches	10
B3317	9. 36	Bentonite	1 inch	26
B3316	9. 35	Shale	1 foot	50
B3315	9. 34	do	3 feet 5 inches	29
B3314T	9. 33	Limestone	3 feet 4 inches	8
B3314M	9. 33	do		20
B3314B	9. 33	do		26
B3313	9. 32	Shale	3 feet 3 inches	24
B3312	9. 31	Mudstone and shale	2 feet 8 inches	28
B3311	9. 30	Shale	2 feet 8 inches	18
B3310	9. 29	Mudstone	1 foot 3 inches	20
B3309	9. 28	Shale	1 foot	3

TABLE 7.—*Selenium content of shale samples from Custer County, S. Dak.*

SEC. 23, T. 3 S., R. 8 E., SOUTHEAST OF HERMOSA (FARM OF JOHN SJOGREN), TOP TO BASE; PORTION ZONE OF PIERRE

Laboratory no.	Field no.	Material	Thickness	Selenium	Laboratory no.	Field no.	Material	Thickness	Selenium
				P. p. m.					*P. p. m.*
B3071	6.6	Shale	1 foot	5	B3068	6.3	Bentonite	¼ inch	5
B3070	6.5	Bentonite	2 inches	2	B3067	6.2	Shale	2 feet	7
B3069	6.4	Shale	18 inches	8	B3066	6.1	Bentonite	10 inches	2

SEC. 23, T. 3 S., R. 8 E., SOUTHEAST OF HERMOSA (FARM OF JOHN SJOGREN), TOP TO BASE; PORTION OF NIOBRARA CHALK PROFILE

B3082	7.12	Chalk	3 feet	12	B3077	7.6	Chalk	1 foot	25
B3081	7.11	do	3 feet	6	B3076	7.5	do	4 feet	20
B3080	7.10	do	3 feet	8	B3075	7.4	do	2 feet	30
B3079	7.9	do	3 feet	8	B3074	7.3	do	2 feet	8
B3078	7.8	do	6 feet	20	B3073	7.2	do	2 feet	28
B3077a	7.7	do	3 feet	30	B3072	7.1	do	2 feet	16

EXAMINATION OF WATER SAMPLES

The areas in which selenium has been found in either soil or vegetation in notable quantities, so far as observed at present, are areas of low rainfall and, in general, little or no percolation of water through the shales can be assumed to have occurred. Surface run-off occurs, however, and this run-off is responsible for the shallow wells which are used on many farms and for the ponds of impounded water. The fall of 1933 was exceptionally dry, and conditions were favorable for a selenium content in water if it ever occurs. A few samples of water were secured from various sources and these were examined for selenium. The results obtained are given in table 8. Included in this table are the results obtained on three samples examined in 1934.

TABLE 8.—*Selenium content of samples of water from Nebraska and South Dakota*

NEBRASKA

Laboratory no.	Field no.	Location	Depth of sample	Selenium	Source
			Feet	*P. p. m.*	
B2500	1	Boyd County, sec. 23, T. 33 N., R. 10 W.	28	0.2	Well; farm of Dale Pierce.
B2501	2	Boyd County, sec. 2, T. 33 N., R. 9 W.	303	0	Well; farm of A. Nellis.
B2503	4	Knox County, sec. 21, T. 33 N., R. 8 W.	18	(1)	Ponca Creek.

TABLE 8.—*Selenium content of samples of water from Nebraska and South Dakota*—Continued

SOUTH DAKOTA

Laboratory no.	Field no.	Location	Depth of sample	Selenium	Source
B2504	5	Gregory, sec. 10, T. 96 N., R. 69 W.	18	0.20	Well; farm of Joseph Huffley.
B2505	6	Gregory, sec. 3, T. 96 N., R. 69 W.	303	.03	Well; farm of T. O. Johnson.
B2506	7	----do----------	----------	.00	Stream; ¼ mile southwest of T. O. Johnson house.
B2507	8	Gregory, sec. 33, T. 96 N., R. 69 W.	600	.00	Well; farm of Mabel Williams.
B2508	9	Gregory, sec. 34, T. 97 N., R. 69 W.	18	.02	Well; farm of C. S. Smith.
B2509	10	Gregory, sec. 22, T. 97 N., R. 69 W.	17	.00	Well; farm of O. L. Unglub.
B2510	11	Gregory, sec. 25, T. 97 N., R. 69 W.	38	.03	Well; farm of Wm. Flisram.
B2511	12	Gregory, sec. 28, T. 97 N., R. 68 W.	----------	.00	Whetstone Creek.
B2512	13	Gregory, sec. 21; T. 97 N., R. 70 W.	18	.00	Well; farm of T. M. Durfee.
B2513	14	Gregory, sec. 25, T. 97 N., R. 70 W.	----------	.00	Whetstone Creek; Nightingale ranch.
B2514	15	Gregory, sec. 17, T. 99 N., R. 70 W.	----------	.00	Stream fed by artesian well.
B2515	16	Gregory, sec. 31, T. 99 N., R. 71 W.	(2)	(1)	Well; west of Ed Breen house.
B2516	17	Gregory, sec. 14, T. 99 N., R. 72 W.	(2)	.20	Well; farm of Mrs. E. Nordby.
B11721	1	Meade County, sec. 24, T. 9 N., R. 5 E.	----------	.08	Tile drain 18 years old.
B11722	2	Meade County, sec. 13, T. 9 N., R. 5 E.	----------	1.20	Tile drain 1 year old
B11723	3	Meade County, sec. 24, T. 9 N., R. 5 E.	----------	.00	Irrigation water.

[1] Trace. [2] Shallow.

It will be observed that small quantities of selenium are found in the shallow wells and drainage water. This indicates removal of selenium from the soils by leaching. No appreciable quantities are found in deep wells or in running streams. The sample of irrigation water from Meade County, Nebr., (B11723, table 8) may without serious error, be taken as representing the water of Belle Fourche River. The single deep well reported as having a small selenium content probably is in or just beneath the Niobrara chalk.

PYRITES AS THE SOURCE OF SELENIUM

In the course of the examination of the soils and shales in Boyd County, Nebr., Hayes secured a concretion of iron pyrites. On analysis by W. O. Robinson this sample showed a selenium content of 205 p. p. m. while similar samples from other localities showed smaller quantities. These observations led to an examination of a series of samples of sulphide ores collected by T. D. Rice and examined by Williams. A portion of the results was published (*20*). Table 9 contains the results obtained.

The work on sulphide ores, as shown in table 9, is important in that it leads inevitably to the conclusion that selenium may be expected to be present in all soils derived from pyritiferous parent material provided, of course, that it were not removed by percolating waters. Whether such presence results in toxic vegetation grown on such soils depends not only upon the quantity of such residual selenium but upon a number of other factors which remain to be discussed.

TABLE 9.—*Selenium content of pyrites and associated materials from various locations*

Laboratory no.	Material	Location	Selenium
			P. p. m.
	Pyrite (concretionary)	Nebraska	205
	Pyrite (massive)	Utah	15
	Pyrite (crystals)	Colorado	10
	do	Isle of Elba	[1]
	Mispickel	Maine	[1]
B3179	Marcasite in black clay	Mississippi	.3
B3183	Marcasite in clay	do	.6
B3174	Pyrite (concretionary)	Alabama	8
B3192	Pyrite	do	75
B3196	do	Georgia	8
B3197	do	do	50
B3199	do	do	45
B3202	do	do	250
B3203	do	do	110
B3204	do	do	150
B3205	do	do	180
B3207	do	do	80
B3169	do	South Carolina	10
B3170	Pyrite (partly decomposed)	do	55
B3171	Pyrite	do	50
B3209	Pyrhotite	Tennessee	5
B3210	Chalcopyrite	do	10
B3211	Pyrite	do	1
B3212	do	Virginia	15
B3213	do	do	65
B3216	do	do	125
B3464	Pyrite (in serpentine)	do	75
B3465	Pseudomorphs (after pyrites)	do	45
B12543	Copper ore	Utah	7
B12545	Sphalerite	do	25
B13227	Tiemanite ore	do	[2] 132,000
B12151A	do	do	[3] 56,050
B6215	Pyrite	Texas	5
B11446	Carnotite ore	Colorado	85
B11430	Pyritiferous ore	do	115
B11431	Crude sulphur	do	8,350
B11432	Pyrite (crude)	do	320
B11433	Pyrite ore	do	180
B11434	Low-grade zinc ore	do	430
B11435	Crude tellurium ore	do	30
B1438	Pyritiferous shale	do	61
B13770	Low-grade vanadium ore	do	125

[1] Trace. [2] 13.2 percent. [3] 5.6 percent.

THE INVESTIGATIONS OF 1934

The work so far presented in this report formed the basis for the organization of the work for the "open season" of the year 1934. Two lines of attack were planned. One consisted of an intensive sampling of areas definitely known to contain selenium to determine the range of quantities present in both soil and vegetation and the extent of the areas involved. This work was undertaken by F. A. Hayes and John T. Miller, of the Soil Survey. The other was a continuation of the reconnaissance work. This was undertaken by T. D. Rice, senior scientist of the Soil Survey, and J. E. Upp. Unfortunately, the work of the latter was very early terminated by a call to other lines of endeavor. Mr. Rice, however, made an extensive examination of soils, shales, minerals, and vegetation in various States. The results of these investigations are reported, so far as they are available, in subsequent tables (14–25). The analytical work on the samples was carried out by K. T. Williams, H. C. Dudley, R. A. Osborn, H. W. Lakin, and R. W. Harkness.

Independently of the survey work here reported upon, much work has been done designed to determine the toxic and lethal limits of various seleniferous materials; the fate of selenium in the animal body;

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the influence of selenium concentrations in the soil on selenium content in vegetation; the differences shown by plants with reference to selenium absorption; and the influence of sulphur compounds on selenium absorption. These investigations were for the most part carried on in bureaus other than Chemistry and Soils, and reference will be made to them here only so far as they bear on the investigation in hand.

THE FIELD EXAMINATIONS

Hayes and Miller began their work by making an intensive examination of the soils of definite sections which were known to be toxic

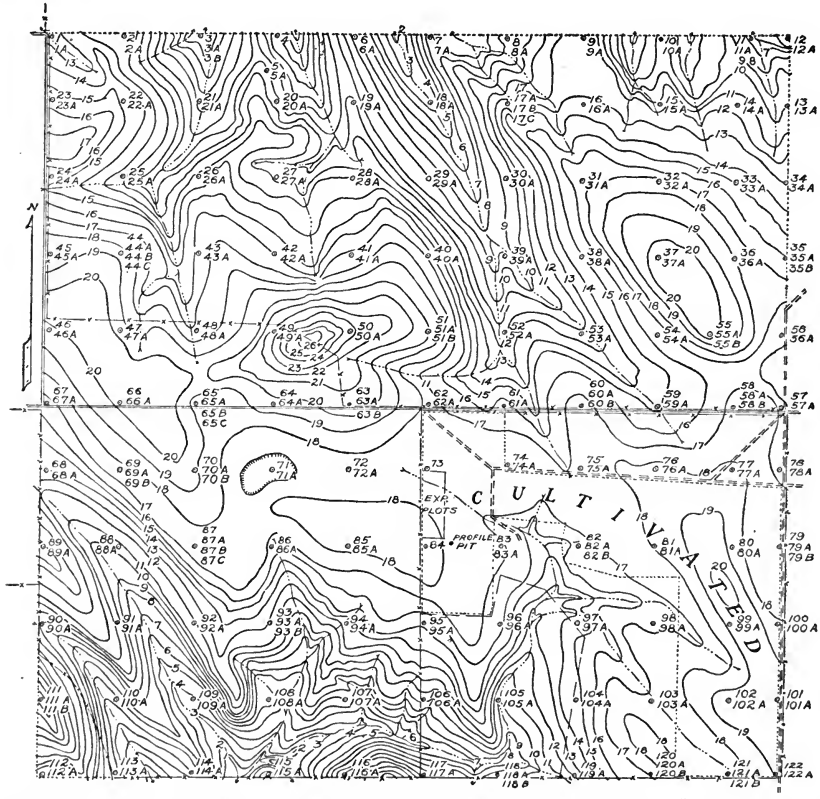

FIGURE 1.—Contour map, sec. 21, T. 100 N., R. 72 W., Gregory County, S. Dak. Contour interval 10 feet. (Reproduction of map made in field.)

either through the investigations of Franke or from the results of the writer. They collected a series of soil samples from each section (square mile) representing the soil to a depth of 6 inches. At the same time they selected vegetation growing as near as possible to the spot where the soil sample was taken. Since it was not known what vegetation was most suitable for investigation they sought to make the selection as varied as possible. In this they were at a very great disadvantage since the summer season of 1934 was marked by severe drought over the whole area examined. In most cases they were able to secure only very poor samples and in many cases none at all.

The areas examined consisted of portions of Boyd County, Nebr., and of Gregory, Lyman, Stanley, and Jones Counties, S. Dak. In the late fall, for reasons later detailed (p. 36), areas in Meade, Butte, Pennington, and Custer Counties also were examined.

Since it was known that the quantity of selenium in the soil varied exceedingly and that the variation in the vegetation was between still wider limits, a few sections were intensively sampled and contour maps were prepared. In this way it was hoped that some clue to the distribution could be obtained by comparison with contours, soil texture, or drainage which would serve as an index for wider surveys. Also a number of soil profiles were taken to determine if any uniformity exists as to variation in depth. In all, 7 sections aggregating about 4,500 acres were sampled in this manner. About 125 samples of soil and from 125 to 150 samples of vegetation were collected from each square mile. The results from a sample section are given in table 10, and the contour map is shown in figure 1.

TABLE 10.—*Selenium content of samples from sec. 21, T. 100 N., R. 72 W., Gregory County, S. Dak.*

Laboratory no.	Field no.	Material	Selenium in—	
			Soil	Vegetation
			P. p. m.	*P. p. m.*
B4507	1	Boyd sandy clay loam, 0–6 inches	13	
B4508	1a	Western wheatgrass		10
B4509	2	Boyd clay loam, 0–6 inches	4	
B4510	2a	Little bluestem		1
B4511	3	Alluvial clay, 0–6 inches	2	
B4512	3a	Wild aster		60
B4513	3b	Young buckbrush		.5
B4514	4	Boyd clay, 0–6 inches	12	
B4515	5	Boyd sandy clay loam, 0–6 inches	3	
B4516	5a	Buckbrush		0
B4517	6	Boyd sandy clay, 0–6 inches	2	
B4518	6a	Little bluestem		0
B4519	7	Boyd clay, 0–6 inches	2.5	
B4520	7a	Little bluestem		0
B4521	8	Boyd clay loam, 0–6 inches	2.5	
B4522	8a	Little bluestem		1
B4523	9	Boyd sandy clay loam, 0–6 inches	2.5	
B4524	9a	Western wheatgrass		20
B4525	10	Boyd clay loam, 0–6 inches	1.5	
B4526	10a	Little bluestem		.5
B4527	11	Boyd clay loam, 0–6 inches	3	
B4528	11a	Mixed grasses		1
B4529	12	Boyd clay, 0–6 inches	2	
B4530	12a	Plant, not identified		2
B4531	13	Boyd clay loam, 0–6 inches	.7	
B4532	13a	Little bluestem		.5
B4533	14	Boyd clay loam, 0–6 inches	9	
B4534	14a	Little bluestem		0
B4535	15	Boyd sandy clay loam, 0–6 inches	4	
B4536	15a	Little bluestem		.5
B4537	16	Boyd sandy clay loam, 0–6 inches	.7	
B4538	16a	Little bluestem		.0
B4539	17	Boyd sandy clay loam, 0–6 inches	5	
B4540	17a	Prairie rose		3
B4541	17b	Soapweed		0
B4542	17c	Little bluestem		1
B4543	18	Boyd clay loam, 0–6 inches	1.5	
B4544	18a	Little bluestem		2
B4545	19	Boyd clay loam, 0–6 inches	4	
B4546	19a	Little bluestem		0
B4547	20	Boyd clay loam, 0–6 inches	1.5	
B4548	20a	Little bluestem		0
B4549	21	Boyd sandy clay loam, 0–6 inches	2	
B4550	21a	Plant, not identified		7
B4551	22	Boyd clay loam, 0–6 inches	2	
B4552	22a	Little bluestem		.5
B4553	23	Boyd sandy clay loam, 0–6 inches	3.5	
B4554	23a	Legume (species unknown)		45

TABLE 10.—*Selenium content of samples from sec. 21, T. 100 N., R. 72 W., Gregory County, S. Dak.*—Continued

Laboratory no.	Field no.	Material	Selenium in—	
			Soil	Vegetation
			P.p.m.	*P.p.m.*
B4555	24	Boyd sandy clay loam, 0–6 inches	2	
B4556	24a	Plant, not identified		50
B4557	25	Boyd sandy clay loam, 0–6 inches	2	
B4558	25a	Plant, not identified		100
B4559	26	Boyd sandy clay loam, 0–6 inches	2	
B4560	26a	Little bluestem		.5
B4561	27	Boyd clay loam, 0–6 inches	2	
B4562	27a	Mixed grasses		.5
B4563	28	Boyd sandy clay loam, 0–6 inches	2	
B4564	28a	Little bluestem		.5
B4565	29	Boyd clay loam, 0–6 inches	7	
B4566	29a	Little bluestem		1
B4567	30	Boyd clay loam	1.5	
B4568	30a	Little bluestem		0
B4569	31	Clay shale, 0–6 inches	2.5	
B4570	31a	Little bluestem		.5
B4571	32	Boyd sandy clay loam	2	
B4572	32a	Little bluestem		1
B4573	33	Boyd sandy clay loam, 0–6 inches	2.5	
B4574	33a	Little bluestem		1
B4575	34	Boyd sandy clay loam, 0–6 inches	2	
B4576	34a	Little bluestem		.5
B4607	35	Boyd sandy clay loam, 0–6 inches	9	
B4608	35a	*Astragulus* (sp?)		2
B4609	35b	Little bluestem		.5
B4610	36	Boyd sandy clay loam, 0–6 inches	9	
B4611	36a	Mixed grasses		45
B4612	37	Boyd sandy clay loam, 0–6 inches	7	
B4613	37a	Little bluestem		1
B4614	38	Boyd clay loam, 0–6 inches	6	
B4615	38a	Little bluestem		2
B4616	39	Boyd clay, 0–6 inches	3	
B4617	39a	Mixed grasses		.5
B4618	40	Boyd clay loam, 0–6 inches	8	
B4619	40a	Little bluestem		1
B4620	41	Boyd sandy clay loam, 0–6 inches	3	
B4621	41a	Little bluestem		.5
B4622	42	Boyd clay, 0–6 inches	3	
B4623	42a	Little bluestem		.5
B4624	43	Boyd clay, 0–6 inches	3	
B4625	43a	Little bluestem		2
B4626	44	Boyd clay loam	11	
B4627	44a	Soapweed		1
B4628	44b	Prairie rose		5
B4629	44c	Little bluestem		1
B4630	45	Boyd sandy clay loam, 0–6 inches	5	
B4631	45a	Mixed grasses		7
B4632	46	Wind-blown clay	5	
B4633	46a	Sunflower heads, no seeds		1
B4634	47	Boyd sandy clay loam, 0–6 inches	4	
B4635	47a	Young western wheatgrass		7
B4636	48	Boyd clay, 0–6 inches	3	
B4637	48a	Young mixed grasses		35
B4638	49	Boyd clay, 0–6 inches	5	
B4639	49a	Mixed grasses		1
B4640	50	Boyd clay loam, 0–6 inches	5	
B4641	50a	Little bluestem		0
B4642	51	Boyd clay, 0–6 inches	2.5	
B4643	51a	Little bluestem		0
B4644	51b	*Astragulus* (sp?)		1
B4645	52	Boyd sandy clay loam, 0–6 inches	4	
B4646	52a	Buffalo grass		12
B4647	53	Boyd clay	6	
B4648	53a	Little bluestem		1
B4649	54	Boyd clay, 0–6 inches	12	
B4650	54a	Little bluestem		2
B4651	55	Boyd clay, 0–6 inches	4	
B4652	55a	*Astragulus* (sp?)		1
B4653	55b	Mixed grasses		1
B4654	56	Boyd clay, 0–6 inches	9	
B4655	56a	Western wheatgrass		40
B4656	57	Boyd clay, 0–6 inches	5	
B4657	57a	Western wheatgrass		3
B4658	58	Boyd clay, 0–6 inches	7	
B4659	58a	*Astragulus* (sp?)		20
B4660	58b	Plant, not identified		10
B4661	59	Boyd clay loam, 0–6 inches	6	

TABLE 10.—*Selenium content of samples from sec. 21, T. 100 N., R. 72 W., Gregory County, S. Dak.*—Continued

Laboratory no.	Field no.	Material	Selenium in—	
			Soil	Vegetation
			P. p.m.	*P. p.m.*
B4662	59a	Western wheatgrass		25
B4663	60	Boyd clay loam, 0–6 inches	5	
B4664	60a	*Astragulus* (sp)		1
B4665	60b	Sedge (*Carex pennsylvanica*)		1
B4666	61	Boyd clay loam, 0–6 inches	6	
B4667	61a	Little bluestem		.5
B4668	62	Boyd clay loam, 0–6 inches	4	
B4669	62a	Little bluestem		1
B4670	63	Boyd clay, 0–6 inches	6	
B4671	63a	Young wild aster		2,670
B4672	63b	Mixed grasses		60
B4673	64	Boyd sandy clay loam, 0–6 inches	4	
B4674	64a	Mixed grasses		35
B4675	65	Boyd clay, 0–6 inches	3	
B4676	65a	Young Russian-thistle		8
B4677	65b	Buffalo grass		10
B4678	65c	Young grasses		9
B4679	66	Boyd clay, 0–6 inches	3	
B4680	66a	Mixture of grasses		30
B4681	67	Boyd clay, 0–6 inches	6	
B4682	67a	Western wheatgrass		3
B4683	68	Wind-blown clay, 0–6 inches	6	
B4684	69	Boyd sandy clay loam, 0–6 inches	3	
B4685	69a	*Astragulus* (sp?)		1
B4686	69b	Western wheatgrass		4
B4687	70	Boyd sandy loam, 0–6 inches	5	
B4688	70a	Mixed grasses		15
B4689	70b	Weed, unidentified		60
B4690	71	Boyd clay loam, 0–6 inches	.5	
B4691	71a	Western wheatgrass		7
B4692	72	Boyd sandy clay loam, 0–6 inches	8	
B4693	72a	Grasses		70
B4694	73	Boyd clay, 0–6 inches	3	
B4695	74	do	5.5	
B4696	74a	Western wheatgrass		30
B4697	75	Boyd clay, 0–6 inches	5	
B4698	75a	Grasses		2
B4699	76	Boyd clay, 0–6 inches	6	
B4700	76a	Grasses		6
B4701	77	Boyd clay, 0–6 inches	8	
B4702	77a	Grasses		1
B4703	78	Boyd clay, 0–6 inches	3	
B4704	78a	Black grama grass		25
B4705	79	Boyd sandy clay loam, 0–6 inches	4	4
B4706	79a	Prairie rose		4
B4707	79b	Sunflower, no seeds		5
B4708	80	Boyd clay loam, 0–6 inches	7	
B4709	80a	Dead Russian-thistle		5
B4710	81	Boyd sandy clay loam, 0–6 inches	6	
B4711	81a	Green Russian-thistle		40
B4712	82	Gray shale	5	
B4713	82a	Milkweed		70
B4714	82b	Prairie rose		20
B4715	83	Boyd sandy clay loam, 0–6 inches	4	
B4716	83a	Western wheatgrass		7
B4717	84	Boyd clay, 0–6 inches	5	
B4718	85	Boyd clay loam, 0–6 inches	6	
B4719	85a	Western wheatgrass		60
B4720	86	Boyd sandy clay loam, 0–6 inches	4	
B4721	86a	Grasses		1
B4722	87	Boyd clay, 0–6 inches	7	
B4723	87a	Weed, not identified		2
B4724	87b	*Astragulus* (sp?)		1
B4725	87c	Little bluestem		1
B4726	88	Boyd clay, 0–6 inches	6	
B4727	88a	Mixed grasses		10
B4728	89	Boyd clay, 0–6 inches	3	
B4729	89a	Grasses		2
B4730	90	Boyd clay, 0–6 inches	1.5	
B4731	90a	Grama grass		1
B4732	91	Boyd clay, 0–6 inches	6	
B4733	91a	Little bluestem		.5
B4734	92	Boyd clay loam, 0–6 inches	2.5	
B4735	92a	Little bluestem		1
B4736	93	Clayey shale, 0–6 inches	3.5	
B4737	93a	Little bluestem		1

TABLE 10.—*Selenium content of samples from sec. 21, T. 100 N., R. 71 W., Gregory County, S. Dak.*—Continued

Laboratory no.	Field no.	Material	Selenium in—	
			Soil	Vegetation
			P. p.m.	*P. p.m.*
B4738	93b	*Astragulus* (sp?)		1
B4739	94	Boyd sandy clay loam, 0–6 inches	5	
B4740	94a	Little bluestem		2
B4741	95	Boyd clay loam, 0–6 inches	3	
B4742	95a	Little bluestem		1
B4743	96	Boyd clay, 0–6 inches	3.5	
B4744	96a	Little bluestem		1
B4745	97	Boyd clay loam, 0–6 inches	2	
B4746	97a	Little bluestem		1
B4747	98	Boyd clay, 0–6 inches	3.5	
B4748	98a	Little bluestem		.5
B4749	99	Boyd sandy clay loam, 0–6 inches	3	
B4750	99a	Young Russian-thistle		20
B4751	100	Boyd clay loam, 0–6 inches	7.5	
B4752	100a	Dead Russian-thistle		7
B4753	101	Boyd sandy clay loam, 0–6 inches	4	
B4754	101a	Young Russian-thistle		35
B4755	102	Boyd clay, 0–6 inches	3	
B4756	102a	Prairie rose		40
B4757	103	Boyd clay, 0–6 inches	6	
B4758	103a	Mixed grasses		3
B4759	104	Boyd clay loam, 0–6 inches	8	
B4760	104a	Little bluestem		1
B4761	105	Boyd clay, 0–6 inches	4	
B4762	105a	Mixed grasses		8
B4763	106	Boyd clay loam, 0–6 inches	1	
B4764	106a	Little bluestem		.5
B4765	107	Boyd clay loam, 0–6 inches	1	
B4766	107a	Little bluestem		1
B4767	108	Boyd clay, 0–6 inches	5	
B4768	108a	Black grama grass		1
B4769	109	Boyd clay, 0–6 inches	3.5	
B4770	109a	Mixed grasses		4
B4771	110	Boyd sandy clay loam, 0–6 inches	7	
B4772	110a	Buckbrush		6
B4773	111	Clayey shale, 0–6 inches	8	
B4774	111a	Prairie rose		6
B4776	112	Boyd clay loam, 0–6 inches	6	
B4777	112a	Little bluestem		1
B4778	113	Boyd sandy clay loam, 0–6 inches	8	
B4779	113a	Big bluestem		1
B4780	114	Boyd clay, 0–6 inches	2	
B4781	114a	Little bluestem		1
B4782	115	Boyd clay loam, 0–6 inches	3	
B4783	115a	Grasses		1
B4784	116	Boyd clay loam, 0–6 inches	5	
B4785	116a	Little bluestem		.5
B4786	117	Boyd sandy clay loam, 0–6 inches	9	
B4787	117a	Big bluestem		1
B4788	118	Boyd clay loam, 0–6 inches	3	
B4789	118a	Buckbrush		12
B4790	118b	Big bluestem		1
B4791	119	Boyd clay, 0–6 inches	11	
B4792	119a	Little bluestem		1
B4793	120	Boyd clay, 0–6 inches	8	
B4794	120a	Little bluestem		1
B4795	120b	Weed, unidentified		35
B4796	121	Boyd sandy clay loam, 0–6 inches	3	
B4797	121a	Prairie rose		25
B4798	121b	Western wheatgrass		30
B4799	122	Boyd sandy clay loam, 0–6 inches	4	
B4800	122a	Young Russian-thistle		35

A study of the data obtained in this manner failed to indicate any general relationships which could be utilized for selection of affected areas by field observation. They revealed two points of interest, however, aside from the direct determination of selenium content. Certain kinds of vegetation are uniformly high and other kinds low in selenium under like conditions. Thus, wild aster, ground cherry, and gumweed are rich in selenium when, under comparable conditions,

buffalo grass, bluestem, grama grass, etc., are relatively poor. It also seemed clear that the general character of a section could be demonstrated by a much smaller number of samples. As a result the num-

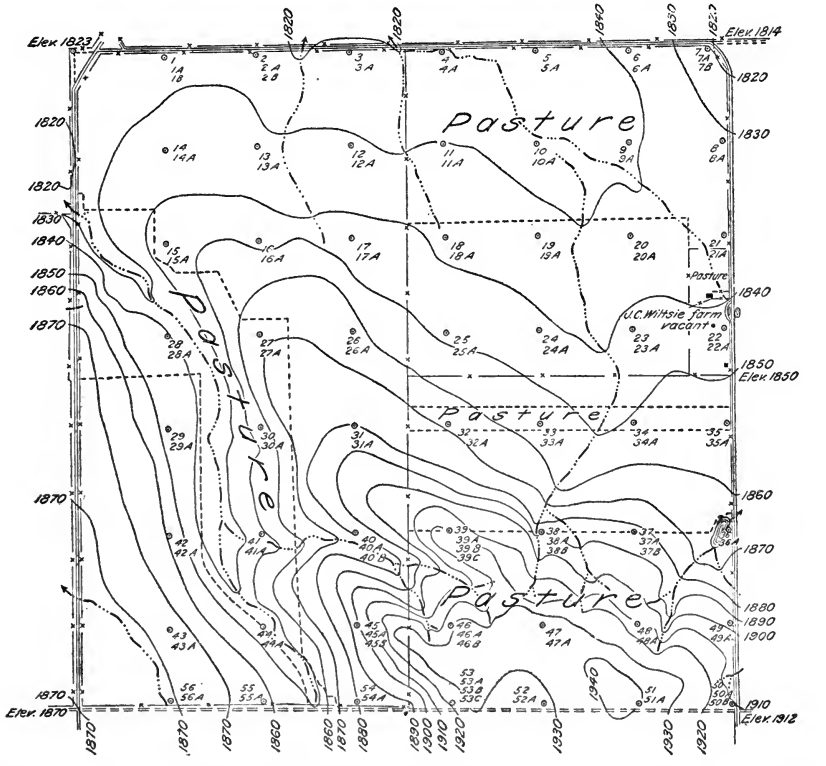

FIGURE 2.—Contour map, sec. 4, T. 108 N., R. 79 W., Lyman County, S. Dak. Contour interval 10 feet. (Reproduction of map made in field.)

ber of samples per square mile was reduced to about 50 of soil and 50 to 75 of vegetation, and this system applied to about 20 sections (about 13,000 acres) in Gregory and Lyman Counties. The results so obtained are illustrated by the data given in table 11 and figure 2.

TABLE 11.—*Selenium content of soils and vegetation from sec. 4, T. 108 N., R. 79 W., Lyman County, S. Dak.*

Laboratory no.	Field no.	Material	Selenium in—		Laboratory no.	Field no.	Material	Selenium in—	
			Soil	Vegetation				Soil	Vegetation
			P.p.m.	*P p.m.*				*P.p.m.*	*P.p.m.*
B7465	1	Boyd clay	1.5	-------	B7472	5	Boyd clay loam	1	-------
B7465	1a	Young wheat	-------	10	B7473	5a	Wheatgrass	-------	3
B7465A	1b	Needlegrass	-------	5	B7474	6	Boyd clay loam	1.5	-------
B7466	2	Boyd clay	1.5	-------	B7475	6a	Needlegrass, dead	-------	.5
B7467	2a	Young wheat	-------	1	B7476	7	Boyd clay loam	2	-------
B7467A	2b	Needlegrass	-------	1	B7477	7a	Grasses	-------	6
B7468	3	Boyd clay	1.5	-------	B7477A	7b	Wild aster	-------	120
B7469	3a	Wheat plants	-------	7	B7478	8	Boyd clay	2	-------
B7470	4	Alluvium	4	-------	B7479	8a	Needlegrass	-------	2
B7471	4a	Needlegrass	-------	5	B7480	9	Boyd clay	3	-------

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TABLE 11.—*Selenium content of soils and vegetation from sec. 4, T. 108 N., R. 79 W., Lyman County, S. Dak.*—Continued

Laboratory no.	Field no.	Material	Selenium in—		Laboratory no.	Field no.	Material	Selenium in—	
			Soil	Vegetation				Soil	Vegetation
			P.p.m.	*P.p.m.*				*P.p.m.*	*P.p.m.*
B7481	9a	Needlegrass		15	B7533	35a	Needlegrass, dead		1
B7482	10	Boyd clay	3		B7534	36	Boyd clay	5	
B7483	10a	Mixed grasses, dead		6	B7535	36a	Needlegrass, dead		18
B7484	11	Boyd clay	1.5		B7536	37	Boyd clay	3.5	
B7485	11a	Mixed grasses, dead		1	B7537	37a	Wild aster		1,300
B7486	12	Boyd clay	1.5		B7538	37b	Wheat		40
B7487	12a	Wheat stubble		1	B7539	38	Alluvium	20	
B7488	13	Boyd clay	1		B7540	38a	Wheatgrass		12
B7489	13a	Wheat stubble		1	B7541	38b	Wheat		40
B7490	14	Boyd clay	1.5		B7542	39	Boyd clay	3	
B7491	14a	Young wheat		2	B7543	39a	Needlegrass		1
B7492	15	Boyd clay	2.5		B7544	39b	Wheat		.5
B7493	15a	Young wheat		45	B7545	39c	Wild aster		5
B7494	16	Boyd clay	1		B7546	40	Boyd clay	4	
B7495	16a	Wheat plants		.5	B7547	40a	Oats, plant		3
B7496	17	Boyd clay	3		B7547A	40b	Wild aster (?)		0
B7497	17a	Young wheat		10	B7548	41	Boyd clay	4	
B7498	18	Boyd clay	2.5		B7549	41a	Wheatgrass		9
B7499	18a	Young cornstalks		2	B7550	42	Boyd clay	3	
B7500	19	Boyd clay	1.5		B7551	42a	Rye plants		20
B7501	19a	Groundcherry		15	B7552	43	Boyd clay	3.5	
B7502	20	Boyd clay	2		B7553	43a	Rye stubble		20
B7503	20a	Young cornstalks		8	B7554	44	Alluvium	3	
B7504	21	Boyd clay	2		B7555	44a	Cordgrass		15
B7505	21a	Needle grass and mixed grasses		2	B7556	45	Boyd clay	3.5	
					B7557	45a	Barley plants		3
B7506	22	Boyd clay	3		B7557A	45b	Wheatgrasses		1
B7507	22a	Needlegrass, dead		15	B7558	46	Boyd clay	4	
B7508	23	Boyd clay	2		B7559	46a	Needlegrass		1
B7509	23a	Barley		12	B7560	46b	Wild aster		5
B7510	24	Boyd clay	3		B7561	47	Boyd clay	3	
B7511	24a	Barley		12	B7562	47a	Needlegrass		2
B7512	25	Boyd clay	2.5		B7563	48	Boyd clay	3	
B7513	25a	Barley		10	B7564	48a	Needlegrass		2
B7514	26	Boyd clay	2		B7565	49	Boyd clay	5	
B7515	26a	Young cornstalks		5	B7566	49a	Needlegrass		1
B7516	27	Boyd clay	2		B7567	50	Boyd clay	2.5	
B7517	27a	Wheatgrasses		4	B7568	50a	Needlegrass, dead		8
B7518	28	Boyd clay	3		B7569	50b	Wild aster		12
B7519	28a	Wheatgrasses		5	B7570	51	Boyd clay	2.5	
B7520	29	Boyd clay	2.5		B7571	51a	Needlegrass		1
B7521	29a	Small-grain stubble		30	B7572	52	Boyd clay	3	
B7522	30	Boyd clay	5		B7573	52a	Needlegrass		40
B7523	30a	Wheatgrass		30	B7574	53	Boyd clay	6	
B7524	31	Boyd clay	6		B7575	53a	Wheatgrass		7
B7525	31a	Barley plants		80	B7576	53b	Needlegrass		2
B7526	32	Boyd clay	5		B7577	53c	Side-oats and grama grass		1
B7527	32a	Needlegrass, dead		10					
B7528	33	Boyd clay	4		B7578	54	Boyd clay	4	
B7529	33a	Needlegrass, dead		3	B7580	55	Boyd clay	2	
B7530	34	Boyd clay	2.5		B7581	55a	Needlegrass, dead		11
B7531	34a	Needlegrass, dead		3	B7582	56	Boyd clay	2.5	
B7532	35	Boyd clay	4		B7583	56a	Sunflower		2.5

Here again it becomes evident that no relationship exists between topographic features and selenium content of either soils or vegetation. It is apparent that all these soil samples are seleniferous and that the selenium content of the vegetation varies widely with the type of vegetation. The selenium in the soils seems to be more uniformly and more widely distributed than had been suspected and it became evident that a more rapid survey must be made if the areas were to be outlined with reasonable speed and cost. It was therefore decided to secure a set of 5 samples of soil and 5 samples of vegetation in every alternate section of a series of townships starting with T. 108 N., R. 79 W. in Lyman County, S. Dak., and ultimately connecting with known areas in Boyd County, Nebr. This work

could not be wholly completed in the season of 1934. The number of samples of vegetation obtained in general slightly exceeds the number of soil samples. In addition to this continuous area a number of more or less isolated sections were sampled by reason of reported intensity of alkali disease or for other reasons.

All of this total number of about 4,000 samples of soil and upwards of that number of samples of vegetation have not, as yet, been analyzed. Analyses of several thousand have been completed. The work on the remainder is progressing rapidly. On the basis of the determinations so far completed the following definite statements are warranted: Every soil sample examined within this area, which totals an indicated acreage of about 500,000, contains selenium in quantities which range from a trace to about 40 p. p. m. The vegetation also contains selenium in amounts varying from scarcely detectable traces up to lethal quantities. It is believed that toxic vegetation is produced in places over the entire area. It is certain that not all of the vegetation is toxic over the whole of any large unit examined. The variation of selenium in the vegetation is extremely wide.

The lower limit of toxicity of vegetation has not yet been determined with sufficient accuracy to warrant definite statements. Unpublished data indicate that toxic effects are produced by quantities of selenium as low as 8.5 p. p. m. of the air-dry diet. The tolerance limit is therefore certainly somewhat lower. For the present, then, if we assume 4 p. p. m. as a tolerance limit, it yet appears that much of the vegetation examined is not toxic.

SOIL PROFILES

As mentioned above, the selenium content of vegetation appears to depend in part upon the character of the soil profile. This relation has at least two variants, the selenium variation with depth and the sulphate content. The latter point will be discussed in a later portion of this report. The selenium content of the soils with variation of depth was investigated by examination of a series of profiles taken in various parts of the areas examined. A selection of these is given in table 12.

TABLE 12.—*Selenium content of selected soil profiles*

PROFILE 1, BOYD CLAY FROM BOYD COUNTY, NEBR., T. 33 N., R. 10 W., SEC. 1

Laboratory no.	Depth	Selenium	Laboratory no.	Depth	Selenium
	Inches	*P.p.m.*		*Inches*	*P.p.m.*
B843	0– 6	3.0	B829	36–42	3.0
B844	6–12	3.0	B830	42–48	3.0
B845	12–18	2.0	B840	48–54	12.0
B846	18–24	2.0	B841	54–60	28.0
B827	24–30	2.0	B842	60–72	24.0
B828	30–36	2.0			

PROFILE 2, MOODY SILT LOAM FROM BOYD COUNTY, NEBR., T. 33 N., R. 9 W., SEC. 7

B823	0– 6	1.5	B849	36–42	2.0
B824	6–12	1.5	B850	42–48	3.0
B825	12–18	1.0	B815	48–54	3.0
B826	18–24	1.0	B816	54–60	3.0
B847	24–30	3.0	B817	60–72	3.0
B848	30–36	2.0	B818	72–84	7.0

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TABLE 12.—*Selenium content of selected soil profiles*—Continued

PROFILE 3, DICKINSON FINE SANDY LOAM, BOYD COUNTY, NEBR., T. 34 N., R. 13 W., SEC. 28

Laboratory no.	Depth	Selenium	Laboratory no.	Depth	Selenium
B2435	0–8	(1)	B2437	15–30	0.0
B2436	8–15	(1)	B2438	30–38	.0

PROFILE 4, BOYD CLAY, LIGHT PHASE, BOYD COUNTY, NEBR., T. 33 N., R. 10 W., SEC. 23

B834	0–6	5.0	B838	24–30	5.0
B835–6	6–18	5.0	B839	30–36	36.0
B837	18–24	4.0			

PROFILE 5, BOYD CLAY FROM GREGORY COUNTY, S. DAK., T. 100 N., R. 72 W., SEC. 21

B391	0–8	8.0	B393	20–29	1.0
B392	8–20	4.0			

PROFILE 6, BOYD CLAY FROM STANLEY COUNTY, T. 3 N., R. 31 E., SEC. 28

B394	0–6	4.0	B396	20–29	7.0
B395	6–20	5.0			

PROFILE 7, BOYD CLAY LOAM FROM LYMAN COUNTY, S. DAK., T. 108 N., R. 78 W., SEC. 36

B12088	0–8	3.5	B12102	36–48	8.0
B12089	8–12	4.0	B12103	48–60	12.0
B12100	24–36	6.0			

PROFILE 8, BOYD CLAY LOAM FROM JONES COUNTY, S. DAK., T. 2 N., R. 30 E., SEC. 35

B12089	0–12	2.5	B12092	36–48	3.0
B12090	12–24	4.0	B12093	48–60	3.5
B12091	24–36	4.0	B12094	60+	3.5

[1] Trace.

A study of these profiles as well as of many similar profiles not reported, reveals no general relationship. The soils of the area have not developed distinct horizonal characteristics. Calcium carbonate is present in all sections and in every profile there is a zone of salt accumulation (mostly gypsum). While in general there appears to be evidence of a tendency toward accumulation of selenium at the surface and also at some point in the profile any definite accumulation cannot be asserted because of the variation of the sections of the Pierre shale. Profile 3 is purposely introduced because while it is only about 12 miles from profile 4, it is free from selenium, while profile 4 is relatively rich. Profile 3 is developed from tertiary sandstone while profile 4 is developed from Pierre shale. The traces of selenium found in the surface of profile 3 are assumed to be due to dust from Pierre sources. The variations with depth, while erratic, may readily be assumed to be one of the causes of variation in the selenium content of the vegetation. This is undoubtedly true but as will be shown (p. 37) a second soil variation and the idiosyncrasies of plants themselves are of far greater influence. One fact stands out distinctly: In the area under investiga-

tion, when selenium is present in the soil, it exists at all depths and appears to some extent in all vegetation. It should also be mentioned that plant residues high in selenium must also have an influence upon successive generations of plants grown on the same areas.

CONTINUATION OF RECONNAISSANCE SURVEY

In the spring of 1934 T. D. Rice undertook a survey of areas in which selenium might be expected to occur on the assumption that it is a residual material from the weathering of pyritic ores or shales. The first portion of his program involved a survey of certain sections of Wyoming, Montana, northern and central South Dakota, and northern Nebraska. In the first portion of this work he was greatly aided by the scientists of the Wyoming Agricultural College and Experiment Station. The method followed was to ascertain districts in which Pierre and other shale formations outcropped and presumably became parent material for soil. Where such districts were found samples of shale, soil, and vegetation were collected and sent to Washington for analysis. In connection with this work several special points of interest developed, which will be discussed in their appropriate setting. At the same time, J. E. Upp undertook a similar examination of the shales and soils of western Nebraska, Kansas, and Oklahoma. Before he had progressed far in this work he was called to another position. In the late summer T. D. Rice made a second excursion into the States of Colorado, Utah, Arizona, and New Mexico. A brief expedition was also made into certain Texas counties by J. T. Miller. In these trips, while no special search was made for sulphide ores, samples were occasionally available and these were sent for examination. The results have already been detailed (pp. 7, 8, and table 9). The data so far available on the samples of soil and vegetation will be presented by States.

SELENIUM IN WYOMING SOILS

ALBANY COUNTY

Seleniferous vegetation was identified in Albany County by Beath and his coworkers (*1*, *2*) and an experimental plot was set up on an area known as the Duell Ranch near Laramie, T. 16 N., R. 74 W., sec. 15. A sketch map of the plots is shown in figure 3. It was planned to use a portion of this area to determine the effect of sulphur on the selenium content of the vegetation. Although, due to various mischances, the experiments were abandoned, Rice carefully sampled the plots for both soil and vegetation. He also sent in a profile sample of soil. Late in the season Beath sent in a second profile sample taken in the wheat plot and a sample of matured wheat grain. These have all been examined for selenium and the results obtained are so illuminating that they are given in full detail in tables 13 and 14.

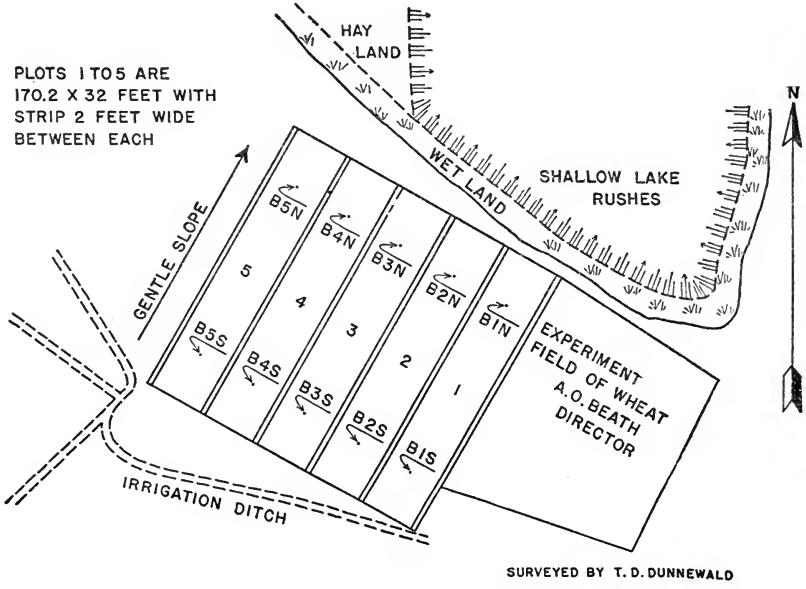

FIGURE 3.—Sketch of experimental plots, Duell Ranch, Wyo.

TABLE 13.—*Selenium content of soils and vegetation from experimental plots on the Duell Ranch, Albany County, Wyo.*

Laboratory no.	Field no.	Material	Selenium in—		Laboratory no.	Field no.	Material	Selenium in—	
			Soil	Vegetation				Soil	Vegetation
			P.p.m.	*P.p.m.*				*P.p.m.*	*P.p.m.*
B4855	B1N	Soil, 0–6 inches	3	-------	B4858	B4N	Soil, 0–6 inches	2	-------
B4860	B1S	do	2	-------	B4865	B4S	do	2	-------
B4840	B1a	Mixed grasses	-------	10	B4849	B4a	Mixed grasses	-------	4
B4841	B1b	*Astragulus missouriensis*	-------	2.5	B4850	B4b	*A. missouriensis*	-------	2
B4842	B1c	*A. bisulcatus*	-------	1,000	B4851	B4c	*A. bisulcatus*	-------	1,460
B4856	B2N	Soil, 0–6 inches	1.5	-------	B4859	B5N	Soil, 0–6 inches	2.5	-------
B4861	B2S	do	2	-------	B4864	B4S	do	1.5	-------
B4843	B2a	Mixed grasses	-------	10	B4852	B5a	Mixed grasses	-------	11
B4844	B2b	*A. missouriensis*	-------	4	B4853	B5b	*A. missouriensis*	-------	2
B4845	B2c	*A. bisulcatus*	-------	800	B4854	B5c	*A. bisulcatus*	-------	940
B4857	B3N	Soil, 0–6 inches	2.5	-------	B5652	1E	Young wheat at Beath's plot	-------	45
B4862	B3S	do	2	-------	B5908	2E	*A. bisulcatus* among wheat	-------	1,110
B4846	B3a	Mixed grasses	-------	10	B12551	3E	Grains from 1E when grown	-------	2
B4847	B3b	*A. missouriensis*	-------	5					
B4848	B3c	*A. bisulcatus*	-------	2,050					

TABLE 14.—*Selenium content of soil profiles on experimental plots on the Duell Ranch, Albany County, Wyo.*

Laboratory no.	Field no.	Material	Selenium in soil	Laboratory no.	Field no.	Material	Selenium in soil
			P. p. m.				*P. p. m.*
B5880	B1w	Soil, 0–2 inches	0.2	B12554	A556	Soil, 3–3½ feet	3
B5881	B2w	Soil, 2–9 inches	.4	B12555	A557	Soil, 3½–4 feet	2.5
B5882	B3w	Soil, 9–21 inches	7	B12556	A558	Soil, 4–5 feet	3
B5883	B4w	Soil, 21–30 inches	4	B12557	A559	Soil, 5–6 feet	3
B5884	B5w	Soil, 30–40 inches	4	B12558	A560	Soil, 6–7 feet	3
B12552	A554	Soil, 0–2 feet	3	B12559	A561	do	3
B12553	A555	Soil, 2–3 feet	4				

Table 13 shows in a most vivid manner the variation in selenium content of different plant species grown in the same soil. The mean value of the selenium content of the surface soils of the five plots sampled by Rice is 2.1 p. p. m.; of the grasses, 9 p. p. m.; of *Astragulus missouriensis*, 3.1 p. p. m.; of *A. bisulcatus*, 1,250 p. p. m. In all cases the content is calculated on the air-dry weight of the samples. This extremely wide divergence of selenium in the vegetation would be unbelievable if it were not confirmed by abundant evidence from supplementary sources in the field and by direct experimental evidence supplied by Hurd-Karrer (*12*). Initially, it was supposed that an explanation might be found in the variation in selenium content of the soil with depth. That such variation occurs has been shown (table 10). If, therefore, variation of this type occurred in this soil and the plants had different feeding areas, the results obtained were not so surprising. The data given in table 15 show that the profiles vary markedly with depth. Nevertheless, it has been rendered satisfactorily clear that the root systems of such plants as wild aster, groundcherry, gumweed, and *A. bisulcatus* high in selenium, apparently do not differ widely enough from those plants showing low selenium content to account for the observed differences.

A second point indicated obscurely by the data in table 14 is the existence of a zone of selenium accumulation. It is indicated in both profiles, despite the differences in scale.

In making further examination of certain sections of Albany County two series of samples were sent to the laboratory. One is from an area immediately southwest of Laramie on both sides of Laramie River. Another area examined is east of Rock River between Cooper Lake and Wheatland Reservoir. Altogether the samples of soil and shale number about 100 and the number of samples of vegetation is somewhat greater. Table 15 presents a selection of these samples together with the location of each. In a general way they may be considered as a cross section running from southwest of Laramie to Rock River.

TABLE 15.—*Selenium content of selected samples of soil, shale, and vegetation from Albany County, Wyo.*

Laboratory no.	Field no.	Location	Material	Selenium in—	
				Soil or shale	Vegetation
				P. p. m.	*P. p. m.*
B4801	A1	Sec. 21, T. 14 N., R. 74 W.	Benton shale	1	
B4802	A2	do.	Soil on shale	.7	
B4809	A6	Sec. 10, T. 13 N., R. 75 W.	Soil on Cloverly shale	0	
B4810	A6a	do.	*Delphinium geyeri*		0
B4821	A12	Sec. 16, T. 16 N., R. 74 W.	Soil, 0–1 inch	.7	
B4822	A12a	do.	Woody aster		120
B4823	A13	do.	Soil, 1–5½ inches	.7	
B4824	A14	do.	Soil, 5½–9 inches	2	
B4827	A18a	Sec. 17, T. 16 N., R. 74 W.	*Astragulus bisulcatus*		1,230
B4828	A18b	do.	*A pectinatus*		2,120
B4831	A21	Sec. 16, T. 16 N., R. 74 W.	Niobrara shale	4	
B4834	A23	do.	Steele shale	6	
B4835	A24a	2 mi. N. of airport, on Niobrara shale.	*A. bisulcatus*		2,000
B5155	A28	Sec. 2, T. 15 N., R. 74 W.	Soil, 0–2 inches	.4	
B5156	A28x	do.	Soil, 2–8 inches	1.5	
B5157	A28a	do.	Mixed grasses		3
B5163	A31	Sec. 5, T. 15 N., R. 74 W.	Soil, 0–6 inches (over Niobrara).	1.5	
B5164	A31a	do.	Mixed grasses		7

TABLE 15.—*Selenium content of selected samples of soil, shale, and vegetation from Albany County, Wyo.*—Continued

Laboratory no.	Field no.	Location	Material	Selenium in—	
				Soil or shale	Vegetation
				P. p. m.	*P. p. m.*
B5164a	A31b	Sec. 5, T. 15 N., R. 74 W.	*A. pectinatus*		1,280
B5164b	A31c	do.	Woody aster		131
B5177	A38	Sec. 12, T. 15 N., R. 75 W.	Soil, 0–6 inches	0.8	
B5178	A38a	do.	Mixed grasses		3
B5178a	A38b	do.	Woody aster		30
B5198	A48	Horn Ranch, T. 22 N., R. 76 W.	Soil, 0–8 inches	1	
B5199	A48a	do.	Woody aster		80
B5200	A49	Boltztoff Ranch, T. 22 N., R. 76 W.	Soil	4	
B5201	A49a	do.	Mixed grasses		15
B5201a	A49b	do.	*A. bisulcatus*		4,300
B5650	A64	T. 27 N., R. 76 W.	Soil, 0–6 inches	1.5	
B5651	A64a	do.	*Oonopsis candensata*		850
B5657	A67		Soil on Niobrara, 0–6 inches.	3.5	
B5658	A67a	T. 27 N., R. 76 W.	*A. pectinatus*		2,890
B5660	A67b	do.	Woody aster		5,390
B5661	A67c	do.	*O. candensata*		9,120
B5662	A67d	do.	*Stanleya pennata*		730
B5663	A67e	do.	Grasses (sparse cover)		75
B5664	A67f	do.	Grasses (thick cover)		25
B5668	A67g	do.	Shale, Niobrara (dark)	55	
B5669	A67h	do.	Ferruginous seam	66	
B5942	A84	Sec. 23, T. 14 N., R. 75 W.	Soil, 0–6 inches		
B5943	A84a	do.	Mixed grasses		6
B5943a	A84b	do.	*A. pectinatus*		1,980
B5943b	A84c	do.	*A. crassicarpus*		6

In the areas represented by table 16 range poisoning is prevalent and in view of the tremendous quantities of selenium found in these samples there would seem little doubt that selenium compounds are responsible for not only the extremely acute poisonings, from which death results within a brief interval after symptoms of trouble develop, but also for the disease locally known as "blind staggers" as well as for the more slowly developing trouble, the alkali disease. In order to make certain that this is true, feeding tests were undertaken in Utah as well as in Washington by the Bureau of Animal Industry. The results obtained will doubtless find publication through other channels but it is proper here to state that both the toxic and lethal effects have been produced by the feeding not only of the organic materials as they occur in vegetation but of extracts presumably free from alkaloids or glucosides, and also by feeding inorganic selenium compounds. In general, it may be remarked that the lethal dose of selenium as it occurs in green vegetation is of the order of magnitude of 2 to 4 mg per animal pound, for certain large animals.

Also table 15 again illustrates the wide variation of selenium absorption by vegetation of different kinds. This is especially well exemplified by the A67 series (a–f) which consists of plants grown on soil derived from Niobrara shale. It indicates the extremely small tendency of native grasses toward selenium absorption, as compared with certain other forms of vegetation. This fact, coupled with the known aversion of animals for seleniferous vegetation, accounts for the fact that animals are able to exist at all in such areas. When drought or overgrazing forces animals to consume toxic vegetation, the results

are naturally very disastrous. It should be repeated that in this area, as in all the others described in States other than South Dakota, there has been no attempt to determine the extent of the area affected. The total of such areas is obviously very great.

CARBON COUNTY

Areas were known in Carbon County where range poisoning occurred. Rice made a collection of samples in various portions of the county in order to determine if this area contains seleniferous soils and vegetation. A portion of the results are given in table 16.

TABLE 16.—*Selenium content of soils, shales, and vegetation in Carbon County, Wyo.*

Laboratory no.	Field no.	Location	Material	Selenium in—	
				Soil or shale	Vegetation
				P. p. m.	*P. p. m.*
B5206	A52	Sec. 19, T. 19 N., R. 78 W.	Soil, 0–6 inches	0.2	
B5207	A52a	do	*Astragulus pectinatus*		840
B5208	A53	Little Medicine Bow River, T. 28 N., R. 77 W.	Soil 0–6 inches	.8	
B5209	A53a	do	Mixed grasses		4
B5214	A56	¾ mile southwest of ranch house on Little Medicine Bow River, T. 28 N., R. 77 W.	Hillside soil, 0–6 inches	1.5	
B5214A	A56a	do	*A. grayii*		4,450
B5215	A56b	do	*A. bisulcatus*		3,140
B5840	C3	9 miles north of Baggs	Soil, 0–6 inches	.0	
B5841	C3a	do	Salt sage		2
B5842	C4	5 miles west of Baggs	Soil	.3	
B5843	C4a	do	Woody aster		6
B5858	C12	14 miles south of Rawlins, T. 19 N., R. 88 W.	Soil, 0–6 inches	.6	
B5859	C12a	do	Woody aster		20
B5864	C15	7 miles south of Muddy Gap	Soil, 0–6 inches	1.0	
B5865	C15a	do	Alfalfa		2
B5866	C15b	do	Woody aster		8
B5867	C15c	do	*A. bisulcatus*		320

The results in table 16 would appear to indicate a virulent area along a portion of Little Medicine Bow River and a very mild degree of intoxication elsewhere in the portions of the county examined.

NATRONA COUNTY

In Natrona County the Caspar-Alcova irrigation project is being developed in an area of soils which are in part developed from shales. A series of samples was taken over a portion of the area. It was the purpose to sample only enough of the area to determine whether any seleniferous soils or vegetation occurs. That such is the case is evident from the data given in table 17. Whether such soil contamination as occurs will result in toxic vegetation when irrigated can only be determined by an intensive examination of soil profiles over the whole area and of the water to be used for irrigation. Also, the resultant effects will be modified by the system of irrigation to be employed.

TABLE 17.—*Selenium content of soil and vegetation in Natrona County, Wyo.*

Laboratory no.	Field no.	Location	Material	Selenium in—	
				Soil or shale	Vegetation
				P.p.m.	*P.p.m.*
B5885	CA1	Sec. 27, T. 35 N., R. 82 W.	Soil, 0–6 inches	1.5	
B5886	CA1a	do	Alfalfa		8
B5886a	CA1b	do	*Astragulus bisulcatus*		3,660
B5887	CA2	Sec. 35, T. 35 N., R. 82 W.	Soil, 0–6 inches	2	
B5888	CA2a	do	Woody aster		200
B5889	CA3	Sec. 1, T. 34 N., R. 82 W.	Soil, 0–6 inches	.7	
B5890	CA3a	do	*A. bisulcatus*		440
B5891	CA4	Sec. 19, T. 34 N., R. 80 W.	Soil, 0–6 inches	0	
B5892	CA4a	do	Mixture of grasses		3
B5893	CA5	Sec. 9, T. 34 N., R. 79 W.	Soil, 0–6 inches	0	
B5894	CA5a	do	Rabbitbrush		12
B5895	CA6	Sec. 17, T. 34 N., R. 79 W.	Soil, 0–6 inches	.6	
B5896	CA6a	do	*A. bisulcatus*		170
B5897	CA7	Sec. 35, T. 36 N., R. 81 W.	Soil, 0–6 inches	0	
B5898	CA7a	do	Grasses		5
B5899	CA8	Sec. 21, T. 35 N., R 81 W.	Soil, 0–6 inches	.6	
B5900	CA8a	do	Mixed grasses		1
B5902	CA9a	Sec. 31, T. 35 N., R. 80 W.	do		1
B5903	CA9x	do	Soil, 0–5 inches	.3	
B5904	CA9y	do	Soil, 5–15 inches	.3	
B5905	CA9z	do	Soil, 24–30 inches	.5	
B5906	CA10	T. 34 N., R. 80 W.	Soil, 0–6 inches	.8	
B5907	CA10a	do	*A. bisulcatus*		3,030

FREMONT COUNTY

In an area about 14 miles northwest of Lysite in Fremont County, a certain small gulch has a local reputation for producing toxic vegetation, and in this small area several thousand sheep are said to have died from forage poisoning within a relatively few years. Rice therefore collected a series of samples. One of these, *Astragulus flavus* Nutt., is said by a ranchman to be "relished by sheep." Table 18 contains the results obtained by analysis.

TABLE 18.—*Selenium content of samples from area 14 miles northwest of Lysite, Fremont County, Wyo.*

Laboratory no.	Field no.	Material	Selenium in—		Laboratory no.	Field no.	Material	Selenium in—	
			Soil or shale	Vegetation				Soil or shale	Vegetation
			P.p.m.	*P.p.m.*				*P.p.m.*	*P.p.m.*
B5992	D9	Soil, 0–6 inches	4		B5988	D5a	Salt sage		480
B5990	D6	do	.4		B5987	D3a	Woody aster		230
B5985	D2	Shale	22		B5990	D7a	Mixed grasses		10
B5984	D1a	Lupine		15	B5991	D8a	*Astragulus*		4,420

After the analyses of table 18 were made, A. B. Clawson, of the Bureau of Animal Industry, collected 500 pounds of the *Astragulus* from the gulch in question and from two adjoining gulches. This material was dried, ground, and thoroughly mixed. The material proved lethal to sheep in relatively small doses. The mixed sample was shown by analysis to contain 1,155 p.p.m. of selenium. This material is lethal to sheep when fed in a quantity of only 0.8 pound of air-dry plant.

UINTA COUNTY

It is nearly as important to know where selenium contamination does not occur as where it does. It is quite impossible to publish negative data in general. However, since in general selenium is found in shales and shale-derived soils, the data from Uinta County are of special interest. A number of samples of the Bridger and Wasatch shales, and of soils developed upon them, were obtained through the kindness of T. D. Dunnewald, of the Wyoming Agricultural Experiment Station; the vegetation samples were a species of vetch (*Astragulus flaviflorus*). The results of some of the analyses of these samples are given in table 19. On the basis of these results the writer is not prepared to state that Bridger-derived soils are always nontoxic but it is evident that in this area at least they are not toxic.

TABLE 19.—*Selenium content of samples from Uinta County, Wyo.*

Laboratory no.	Field no.	Location	Material	Selenium in—	
				Soil or shale	Vegetation
				P.p.m.	*P.p.m.*
B7298	U1R	1 mile east of Church Buttes	Bridger shale, 3 feet	0.4	
B7299	U1S	do	Soil, 0–6 inches	0	
B7297	U1P	do	*Astragulus flaviflorus*		5
B7300	U2R	Sec. 27, T. 16 N., R. 114 W	Bridger shale	.8	
B7301	U2S	do	Soil, 0–6 inches	0	
B7302	U2P	do	*A. flaviflorus*		4
B7713	U4R	Sec. 2, T. 17 N., R. 115 W	Bridger shale		
B7712	U4S	do	Soil, 0–6 inches	.1	
B7711	U4P	do	*A. flaviflorus*		0
B7714	U5R	Sec. 19, T. 17 N., R. 114 W	Bridger shale		
B7715	U5S	do	Soil, 0–6 inches		
B7716	U5P	do	*A. flaviflorus*		0
B7718	U6R	Sec. 24, T. 18 N., R. 116 W	Wasatch shale		
B7717	U6S	do	Soil, 0–6 inches		
B7719	U6P	do	*A. flaviflorus*		2
B7720	U7R	Sec. 7, T. 17 N., R. 115 W	Wasatch shale		
B7721	U7S	do	Soil, 0–6 inches		
B7722	U7P	do	*A. flaviflorus*		3
B8208	U8R	Sec. 22, T. 17 N., R. 117 W	Wasatch shale		
B8209	U8S	do	Soil, 0–6 inches		
B8210	U8P	do	*A. flaviflorus*		0
B7294	S1R	Sweetwater County, ½ mile east of Granger.	Bridger shale	0	
B7295	S1S	do	Soil, 0–6 inches	0	
B7296	S1P	do	*A. flaviflorus*		2

MISCELLANEOUS DATA FROM WYOMING

Rice also made a collection of a series of samples from spots in a number of counties in Wyoming including Hot Springs, Washakie, Sheridan, Campbell, and Crook Counties. The examination of these samples revealed no soils or vegetation of toxic character, though in every case where shale-derived soils were examined, quantities of selenium were found ranging between 0.2 and 1 part per million. No vegetation of toxic character appeared. This does not demonstrate that no toxic areas exist in these counties but does indicate relative freedom from injurious conditions. Unfortunately, the reconnaissance did not include Niobrara County, where, there is some reason to believe, a toxic area exists.

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SELENIUM IN MONTANA SOILS

The continuance of the reconnaissance survey included a very small transect in Carter County, Mont. The examination of the samples revealed the presence of toxic soils and vegetation in the area. Details are given in table 20. How extensive the areas of seleniferous soils are in Montana is unknown, but geological and soil data indicate that there may be considerable areas in more than one portion of the State.

TABLE 20.—*Selenium content of soils and vegetation in Carter County, Mont.*

Laboratory no.	Field no.	Location	Material	Selenium in—	
				Soil or shale	Vegetation
				P. p. m.	*P. p. m.*
B6292	E5	4 miles east of Ridge	Pierre clay, 0–6 inches	0.4	
B6292	E5a	do	Mixed grasses		0
B6293	E6	12 miles east of Ridge	Pierre clay, 0–6 inches	.8	
B6294	E6a	do	Sage brush		1.5
B6294A	E7a	7 miles north of E–6	*Astragulus bisulcatus*		510
B6295	E8x	18 miles east of Ridge	Graneros shale	.5	
B6296	E3y	do	Concretions in shale	4	
B6297	E9	7 miles northeast of Alzada	Pierre soil, 0–6 inches	1	
B6298	E9a	do	*A. bisulcatus*		200
B6299	E10a	13 miles northeast of Alzada	do		590
B6300	E11	13.5 miles northeast of Alzada	Alluvial soil, 0–6 inches	1	
B6301	E11a	do	*A. bisulcatus*		515
B6302	E12a	19 miles northeast of Alzada	do		157
B6303	E14		Soil, 0–6 inches	.5	
B6303a	E14a		Mixed grasses		3.5

MISCELLANEOUS DATA FROM SOUTH DAKOTA

In the northern part of South Dakota west of the Missouri River, very large areas of soil are derived from Pierre shale. There are but few reports of range poisoning. A portion of the area is covered with soils derived from tertiary material which contains no selenium. East of the river the soils are derived from glacial drift, which is also selenium-free, but adjacent to the river especially, the soil parent material is mixed with much shale. In the southern portion of this area many reports of cases of alkali disease have been received. With the purpose of ascertaining if all this area must be included in an intensive examination of the soils and vegetation, Rice made a collection of samples, at rather wide intervals, for the most part, throughout this area. The results obtained cannot be given in detail but a representative group is presented in table 21.

TABLE 21.—*Selenium content of samples from miscellaneous areas in western South Dakota*

BUTTE COUNTY

Laboratory no.	Field no.	Location	Material	Selenium in—	
				Soil or shale	Vegetation
				P. p. m.	*P. p. m.*
B6310	E20	19 miles northwest of Belle Fourche	Soil (with shale), 0–6 inches	2	
B6310A	E20a	do	Mixed grasses		1
B6311	E21	10 miles northwest of Belle Fourche	Soil, 0–6 inches	2	
B6311A	E21a	do	Mixed grasses		1.5
B6863	F17	16 miles northeast of Newell	Gumbo soil	.7	
B6864	F17a	do	Ragweed		1

MEADE COUNTY

B6861	F16	1 mile northeast of Sulphur	Gumbo soil, 0–6 inches	0.5	
B6862	F16a	do	Mixed grasses		3
B6865	F18	Sec. 11, T. 3 N., R. 9 E	Pierre loam, 0–6 inches	.7	
B6866	F18a	do	Alfalfa		1
B6867	F19	Sec. 12, T. 3 N., R. 10 E	Pierre clay, 0–8 inches	.7	
B6868	F19a	do	Ragweed		0
B6888	F31	8 miles north of Viewfield	Gumbo soil, 0–6 inches	2.5	
B6889	F31a	do	Unidentified plant		6
B6899	F37x	2 miles south of Faith	Shale	.5	
B6900	F38	North of Faith	Heavy clay soil, 0–8 inches	.5	
B6901	F38a	do	Unidentified plant		3

PENNINGTON COUNTY

B6876	F25	2 miles north of Underwood	Soil, 0–6 inches	0.7	
B6877	F25a	do	Ragweed		1
B6875	F24a	5 miles northeast of Rapid City	Grasses		10
B6875A	F24b	do	*Astragulus bisulcatus*		870
B6878	F26	4 miles north of Underwood	Colluvial Pierre soil	1	
B6879	F26a	do	Ragweed		1

ZIEBACH COUNTY

B6325	F3	½ mile north of Moreau River	Soil, 0–6 inches	0.0	
B6326	F3a	do	Mixed grasses		0.0
B6858	F15	4 miles north of Red Elm	Soil, 0–6 inches	.5	
B6859	F15x	do	Soil, 18–24 inches	.2	
B6860	F15a	do	Mixed grasses		.5

DEWEY COUNTY

B6227	F4	North of Eagle Butte	Shale	1.5	
B6328	F4a	do	Mixed grasses		1
B6331	F6	8 miles south of junction of highways 12 and 18.	Pierre clay, 0–6 inches	1.5	
B6332	F6a	do	Mixed grasses		0
B6333	F7	5 miles south of junction of highways 12 and 18.	Soil, 0–6 inches	.8	
B6334	F7a	do	Mixed grasses		1.5
B6339	F10	1 mile north of Laplant	Soil, 0–6 inches	.2	
B6340	F10a	do	Mixed grasses		0
B6849	F12x	2 miles north of Promise	White shale	.5	
B6850	F12y	do	Yellow shale	4	
B6851	F12z	do	Black shale	6	
B6908	F43x	Forest City bridge	Pierre shale	2	
B6911	F45y	do	Brown shale	4	
B6335	F9	2 miles southwest of Promise	Soil, 0–6 inches	1	
B6336	F9a	do	Mixed grasses		7

WALWORTH COUNTY

B6902	F39	½ mile northeast of Sitka	Shale (mixed with glacial material).	1	
B6903	F40x	10 miles west of Asaka	Shale	1.5	
B6904	F41	4 miles south of Asaka	Gumbo shale, 0–10 inches	1	
B6905	F41a	do	Dead grasses		3
B6906	F41x	do	Shale	1.5	

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TABLE 21.—*Selenium content of samples from miscellaneous areas in western South Dakota*—Continued

SULLY COUNTY

Laboratory no.	Field no.	Location	Material	Selenium in—	
				Soil or shale	Vegetation
				P. p. m.	*P. p. m.*
B6935	G13	25 miles west of Oneida	Pierre clay	0.5	
B6936	G13a	do	Wheat grasses		6
B6937	G14x	25.5 miles west of Oneida	Shale	.4	
B6938	G14y	do	Ferruginous shale	6	
B6939	G14a	do	Unidentified plant		4

HUGHES COUNTY

B6912	G1	Sec. 27, T. 112 N., R. 76 W	Williams loam, 0–6 inches	0.1	
B6913	G1a	do	Lambsquarters		1
B6914	G2	Sec. 15, T. 110 N., R. 76 W	Gumbo soil, 0–8 inches	.5	
B6915	G2a	do	Russian-thistle		0
B6917	G3y	Sec. 26, T. 110 N., R. 76 W	Ferruginous shale	2	
B6918	G4	Sec. 6, T. 109 N., R. 75 W	Colluvial soil, 0–6 inches	.5	
B6919	G4a	do	Wild aster		40
B6923	G7	Sec. 21, T. 110 N., R. 74 W	Gumbo soil, 0–6 inches	.6	
B6926	G8a	Sec. 30, T. 110 N., R. 73 W	Unidentified plant		.5
B6932	G11x	Sec. 17, T. 109 N., R. 73 W	Shale and soil, 0–6 inches	3	
B6933	G11a	do	Wild aster		155

HYDE COUNTY

B6928	G9	Sec. 21, T. 110 N., R. 73 W	Gumbo soil (eroded), 0–6 inches.	0.7	
B6929	G9a	do	Mixed grasses		6
B6932	G11x	Sec. 17, T. 109 N., R. 73 W	Shaly soil, 0–6 inches	3	
B6933	G11a	do	Wild aster		
B6944	H2	Hale farm	Soil, 0–8 inches	.8	
B6945	H2a	do	Mixed grasses		4
B6946	H2b	do	Wild aster		130
B6970	H13	do	Soil, 0–8 inches	2	
B6971	H13a	do	Mixed grasses		10
B6990	H21	do	Soil (near pond), 0–8 inches	1.5	
B6991	H21a	do	Western wheatgrass		3
B7012	H31	Sec. 7, T. 110 N., R. 72 W	Soil, 0–8 inches	1	
B7013	H31a	do	Wheatgrasses		1
B7016	H33	Sec. 30, T. 110 N., R. 72 W	Soil, 0–8 inches	1	
B7017	H33a	do	Mixed grasses		2

BRULE COUNTY

B7303	J1	1 mile northwest of Bijou Hill post office.	Soil, 0–10 inches	1.5	
B7305	J1a	do	Pigweed		1
B7306	J2x	7 miles southwest of Chamberlain	Shale	8	
B7308	J3x	West of Bijou Hill post office	do	1	
B7309	3a	do	Sunflower		1
B7312	J5	¼ mile east of Bijou Hill post office	Soil, 0–10 inches	1	
B7317	J5a	do	Grasses		1
B7318	J5b	do	Russian-thistle		1

CHARLES MIX COUNTY

B7323	J9	Sec. 31, T. 99 N., R. 70 W	Soil, 0–8 inches	4	
B7324	J9a	do	Lambsquarters		45
B7325	J10	10½ miles south of Platte	Soil, 0–8 inches	.4	
B7326	J10a	do	Mixed grasses		0
B7328	J11y	4½ miles southwest of Wheeler Bridge.	Clay, 0–8 inches	6	
B7331	J11a	do	Grasses		1

SELENIUM IN COLORADO SOILS

After completing the sampling of the areas examined, Rice renewed his general survey by making similar investigations in Colorado. It was already known that seleniferous vegetation is produced in Colorado. A. B. Clawson, of the Bureau of Animal Industry, furnished two samples of vegetation from Yuma and Lincoln Counties which contained selenium, and Rice, while in Wyoming, secured two samples from the Fort Collins area. These and other samples are shown in table 22. In Colorado at the time the samples were collected, which was late in the season, suitable samples of vegetation were very difficult to secure, and the results do not indicate satisfactorily the distribution of seleniferous soils within the State. They do indicate, however, several localities that deserve fuller investigation. Incident to this trip Rice also secured a considerable number of ores containing pyrite or other sulphide minerals and these are reported in table 9. During the progress of the work a composite sample of water from the Colorado River, near the mouth of the Gunnison, was obtained from W. D. Collins of the United States Geological Survey, and found to contain 0.015 p.p.m. of selenium. The facts detailed would seem to render imperative a closer examination of the soil areas of Colorado which are derived from shales and sulphide minerals.

TABLE 22.—*Selenium content of soils and vegetation from Colorado*

Laboratory no.	Field no.	Location	Material	Selenium in—	
				Soil or shale	Vegetation
				P. p. m.	*P. p. m.*
B3608	19–34	Yuma County, Wray	*Asclepius eumila* (whorled milkweed).		5
B3617	25–40	Lincoln County, Hugo	*Oxytropis pinnata* (white loco).		400
B11382	L3x	Morgan County, 14 miles north of Fort Morgan.	Pierre shale	0	
B11383	L4x	Morgan County, 9 miles north of Fort Morgan.	do	.5	
B11396	L11	Morgan County, 16 miles south of Fort Morgan.	Pierre soil, 0–6 inches	.3	
B11380	L1x	Logan County, 12 miles north of Sterling.	Pierre shale	.0	
B11381	L2x	Logan County, 9 miles north of Sterling.	do	2	
B5918	A73	Larimer County, Fort Collins	Soil, 0–6 inches	1	
B5919	A73a	do	*Stanleya pinnata*		20
B5921	A74a	do	*Astragulus bisulcatus*		230
B11385	L5	Larimer County, 7 miles north of Laporte.	Soil, 0–6 inches	2	
B11386	L5a	do	Alfalfa		12
B11387	L6	Larimer County, sec. 21, T. 8 N., R. 69 W.	Soil (irrigated), 0–12 inches	5	
B11388	L6a	do	Ragweed		1
B11397	L12x	Adams County, 19 miles south of Fort Morgan.	Pierre shale	.2	
B11398	L13	Adams County, 23½ miles south of Fort Morgan.	Pierre soil, 0–12 inches	.6	
B11399	L13x	do	Pierre shale	.5	
B11415	L26x	Otero County, 3 miles south of Ayer	Niobrara shale	.5	
B11400	L14x	Las Animas County, 3 miles south of Aguilar.	Shale	.4	
B11401	L15x	Las Animas County, 5 miles south of Aguilar.	do	.5	
B11402	L16x	Las Animas County, 7 miles north of Trinidad.	do	1.5	
B11403	L17	Las Animas County, 11 miles east of Trinidad.	Soil, 0–12 inches	1	
B11404	L17a	do	Whorled milkweed		2
B11405	L17b	do	Forage plant (not identified).		30

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TABLE 22.—*Selenium content of soils and vegetation from Colorado*—Continued

Laboratory no.	Field no.	Location	Material	Selenium in—	
				Soil or shale	Vegetation
				P. p. m.	*P. p. m.*
B11406	L18x	Las Animas County, 11¼ miles east of Trinidad.	Shale	0.6	
B11408	L20a	Las Animas County, 18 miles east of Trinidad.	Vetch		10
B11409	L21a	do	Ragweed		3
B11412	L24	Las Animas County, Winger ranch	Soil, 0–12 inches	1.5	
B11413	L24a	do	Russian-thistle		8
B11414	L25x	Las Animas County, 25 miles north of Trinidad.	Niobrara shale	8	
B13729	L28	Las Animas County, 1 mile north of Trinidad.	Irrigated soil, 0–6 inches	1	
B13730	L29	Los Animas County, 4 miles east of Trinidad.	do	.7	
B13731	L29a	do	Alfalfa		0
B11416	M1x	Grand County, 44 miles southeast of Steamboat Springs.	Shale	3	
B11417	M2x	Grand County, 36 miles southeast of Steamboat Springs.	do	23	
B11418	M3x	Routt County, 3 miles west of Steamboat Springs.	do	4	
B11419	M3a	do	Plant (not identified)		2
B11422	M5x	Moffat County, 8 miles north of Craig.	Shale	1.5	
B11424	M5z	do	Sandy shale	2.5	
B11428	M7x	Rio Blanco County, 13 miles north of Meeker.	Niobrara shale	1.5	
B11454	M25x	Garfield County, 25 miles northwest of DeBeque.	Shale	5	
B11450	M24x	Mesa County, 2 miles north of Mesa	Sandy shale	6	
B11453	M24y	do	Blue shale	12	
B11452	M24a	do	Plant (not identified)		2
B11453	M24b	do	do		0
B12105	M28x	Mesa County, 4½ miles north of Loma.	Shale	6	
B12106	M28a	do	Plant (not identified)		4
B12111	M33x	Mesa County, ¼ mile east of State Line.	Mancos shale	4	
B14439	25	Mesa County, 6.5 miles east of Fruita	Salt crust	260	
B14443	29	Mesa County, 1 mile west of Loma	do	16	
B11438	M17x	Montrose County, 18 miles east of Montrose.	Shale	4	
B11439	M17y	do	Salts from shale	18	
B11443	M19	Montrose County, 1½ miles west of Redvale.	Alluvial soil, 0–6 inches	1	
B11444	M19a	do	Plant (not identified)		7
B11447	M22x	Montrose County, 1.6 miles east of Naturita.	Shale	61	
B13770	91766	Montrose County, 3 miles south of Naturita.	Sandstone shale (vanadium ore).	125	
B11431	M9x	Gunnison County, Vulcan Mine	Crude sulphur	8,350	
B11434	M13x	Gunnison County, Good Hope Mine	Telluride ore	430	
B11437	M16x	Gunnison County, 5 miles north of Almont.	Shale	.8	
B11449	M23x	Ouray County, 6 miles west of Ridgeway.	do	.6	
B13769	91766	San Miguel County	Vanadium ore	85	

SELENIUM IN NEBRASKA, KANSAS, AND OKLAHOMA SOILS

A series of samples of soils, shales, and vegetation has also been secured from Nebraska, Kansas, and Oklahoma. These do not present an adequate survey of the situation and only serve to indicate the need of further investigation. The data are presented in table 23.

TABLE 23.—*Selenium content of samples from Nebraska, Kansas, and Oklahoma*

NEBRASKA

Laboratory no.	Field no.	Location	Material	Selenium in—	
				Soil or shale	Vegetation
		Boyd County:		*P.p.m.*	*P.p.m.*
B3439	1	Sec. 8, T. 33 N., R. 9 W.	Boyd clay loam, 0–6 inches	1.5	
B6220	1b	do	Young oats		4
B3964	16	do	Boyd clay loam, 0–6 inches	2	
B6399	16b	do	Russian-thistle		5
B4005	32	do	Boyd clay loam, 0–6 inches	2.5	
B6290	32b	do	Wild aster		1,210
B1219	H24	do	Boyd clay loam, 0–6 inches	2	
B6400	H24b	do	Russian-thistle		12
B2417	P10	do	Boyd clay, 0–6 inches	.7	
B6248	S106	do	Russian-thistle		20
B3767	19	Sec. 17, T. 33 N., R. 9 W.	Boyd clay loam, 0–6 inches	7	
B6224	19b	do	Wild aster		12
B3775	22	do	Boyd clay loam, 0–6 inches	13	
B6225	22b	do	Wild aster		12
B3863	61	do	Boyd clay loam, 0–6 inches	5.5	
B6235	61b	do	Young oats		10
B6178		Sec. 2, T. 33 N., R. 9 W.	Boyd silt loam, 0–6 inches	14	
B6381		do	Young wheat		6
B6200		Sec. 35, T. 33 N., R. 9 W.	Dickinson fine sandy loam	0	
B6380		do	Russian-thistle		.5
B6268		Sec. 27, T. 33 N., R. 9 W.	Moody silt loam	.3	
B6397		do	Young wheat		1
B6262		Sec. 16, T. 33 N., R. 9 W.	Boyd fine sandy loam	3.5	
B6385		do	Kuhnia		7
		Knox County:			
B6202		Sec. 35, T. 33 N., R. 8 W.	Moody silt loam, 0–6 inches	.4	
B6381		do	Young foxtail		1
B6205		Sec. 7, T. 33 N., R. 8 W.	Boyd silt loam, 0–6 inches	.5	
B6368		do	Wild aster		45
B6206		do	Boyd silt loam, 0–6 inches	1.5	
B6209		do	Wheat hay		7
B8248	M2	Sec. 21, T. 33 N., R. 7 W.	Lamoure silty clay, 0–6 inches	4	
B8250	M2a	do	Pigweed		5
B7342	J16	Sec. 21, T. 32 N., R. 2 W.	Chalky shale	10	
B7347	J18x	Sec. 18, T. 32 N., R. 5 W.	do	27	
B7350	J20	Sec. 29, T. 32 N., R. 5 W.	Boyd clay loam, 0–12 inches	2.5	
B7351	J20a	do	Mixed grasses		1
		Cedar County:			
B7337	J13	Sec. 6, T. 32 N., R. 1 W.	Boyd clay loam, 0–12 inches	1	
B7335	J13a	do	Ragweed		2
B7336	J13b	do	Lambsquarters		3
B7338	J14	Sec. 21, T. 33 N., R. 1 W.	Boyd clay loam, 0–8 inches	.7	
B7339	J14a	do	Lambsquarters		4
		Webster County:			
B7739	R1x	Sec. 16, T. 1 N., R. 9 W.	Niobrara chalk	8	
B7724	R1a	do	Ironweed		3
B7725	R1b	do	Weed (not identified)		4
B7740	R2	Sec. 2, T. 1 N., R. 11 W.	Immature soil, 0–6 inches	10	
B7741	R2x	do	Niobrara chalk	9	
B7726	R2a	do	*Astragulus*		540
B7727	R2b	do	Sweetclover		50
		Franklin County:			
B7742	R3x	1 mile west of Riverton	Niobrara chalk	10	
B7728	R3a	do	Weed (not identified)		4
B7743	R4x	Sec. 5, T. 1 N., R. 14 W.	Niobrara chalk	11	
B7729	R4a	do	Lambsquarters		1
		Harlan County:			
B4373		Sec. 15, T. 1 N., R. 17 W.	Niobrara shale	20	
B4374		Sec. 2, T. 1 N., R. 17 W.	Pierre shale	8	
B4375		Sec. 21, T. 1 N., R. 17 W.	do	31	
B7745	R6x	Sec. 14, T. 1 N., R. 17 W.	do	20	
B7731	R6a	do	Sunflower		0
B7746	R7x	At bridge south of Alma	Pierre shale	7	
B7732	R7a	do	Sweetclover		2
		Furnas County:			
B7747	R8x	Sec. 23, T. 2 N., R. 21 W.	Niobrara chalk	6	
B7733	R8a	do	Grasses		1
		Hitchcock County:			
B7749	R9x	Sec. 5, T. 2 N., R. 33 W.	Leached Pierre shale	.2	
B7733A	R9a	do	Ragweed		2
B7734	R9b	do	Grasses		1
		Dundy County:			
B7750	R10x	Sec. 3, T. 1 N., R. 37 W.	Pierre shale	3.5	
B7735	R10b	do	Plant (not identified)		1

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TABLE 23.—*Selenium content of samples from Nebraska, Kansas, and Oklahoma*—Continued

KANSAS

Laboratory no.	Location	Material	Selenium in—	
			Soil or shale	Vegetation
			P. p. m.	*P. p. m.*
B5369	Gove County, 1½ miles west and 11 miles south of Collyer.	Pierre clay, 0–6 inches	14	
B5370	do	Vegetation		910
B5257	Logan County, McAllister Buttes	Soil, 0–6 inches	23	
B5258	Logan County, top of McAllister Buttes	Shale, 0–10 inches	6	
B5259	Logan County, McAllister Buttes	Pierre shale, 10–20 inches	8	
B5260	do	Pierre shale, 20–30 inches	8	
B5261	do	Pierre shale, 30–40 inches	8	
B5262	do	Pierre shale, 40–50 inches	23	
B5374	do	Vegetation		3,700
B5280	do	Concretions	1.5	
B5379	do	Vegetation		15
B5279	Wallace County, Upper Salt Grass Shale	Soil, 0–6 inches	2.5	
B5375	do	Vegetation		7
B5240	Wallace County, Upper Salt Grass Shale no. 3.	Shale	10	
B5241	Wallace County, Upper Salt Grass Basal	do	1	
B5372	do	Vegetation		5
B5298	Wallace County, sec. 11, T. 13 S., R. 42 W.	Weskan shale	.5	
B5376	do	Vegetation		12
B5293	Hamilton County, Bridge Creek	Soil, 0–6 inches	.5	
B5285	do	Shale	.3	
B5286	do	Ferruginous shale	1	
B5381	do	Vegetation		3
B5287	Hamilton County, ½ mile north, ½ mile east of Medway.	Soil, 0–6 inches	.5	
B5382	do	Vegetation		10
B5269	Barber County, Sun City	Gypsum soil, 0–6 inches	.4	
B5377	do	Vegetation		12
B5299	Barber County, ½ mile west, 1½ miles west of Sun City.	Soil, 0–6 inches	.4	
B5380	do	Vegetation		2
B5297	Barber County, Hazelton	Soil, 0–6 inches	.7	
B5383	do	Vegetation		2
B5270	Comanche County, 4 miles south of Belvedere.	Gypsum	.0	
B5271	do	Kiowa shale	1.5	
B5273	do	Gypsum in shale	1.5	
B5384	Comanche County, Dog Creek Shale	Vegetation		5
B5292	Clark County, sec. 9, T. 33 S., R. 21 W.	Soil, 0–6 inches	.5	
B5271	do	Vegetation		910
B5256A	Clark County, sec. 35, T. 32 S., R. 24 W.	Soil, 0–6 inches	.4	
B5373	do	Vegetation		15

OKLAHOMA

B5310	Grady County, 3½ miles west of Pocasset.	Soil, 0–6 inches	0.3	
B5388	do	Vegetation		6
B5332	9½ miles east of Cement	Soil, 0–6 inches	.3	
B5385	do	Vegetation		6
B5329	1 mile west of Cyril	Soil, 0–6 inches	.5	
B5388	do	Vegetation		7
B5330	5 miles east of Cyril	Soil, 0–6 inches	.2	
B5389	do	Vegetation		9
B5331	½ mile east of Cyril	Shale	14	
B5334	6 miles east of Norman	Soil, 0–6 inches	.2	
B5386	do	Vegetation		8

SELENIUM IN UTAH, ARIZONA, AND NEW MEXICO SOILS

A series of samples from Utah, Arizona, and New Mexico have been examined. They do not present a connected series, and only serve to indicate that enough data have been assembled to show that a closer investigation must be made. A selection of these is given in table 24.

TABLE 24.—*Selenium content of soils and vegetation from Utah, Arizona, and New Mexico*

UTAH

Laboratory no.	Field no.	Location	Material	Selenium in—	
				Soils	Vegetation
				P. p. m.	*P. p. m.*
B12137	N14x	1 mile east of Jensen	Mancos shale	5	-------
B12135	N15y	5 miles east of Jensen	do	3	-------
B12115	N3x	6 miles west of Cisco	do	8	-------
B12539	N34x	9 miles west of Moab	Red shale	.2	-------
B12540	N34a	do	Unidentified plant	-------	0.2
B12542	N36x	13 miles north of Moab	Green shale	8	-------
B12520	N24x	1½ miles west of Desert Switch	Mancos shale	.2	-------
B12521	N23a	do	Mormon tea	-------	.5
B12522	N24b	do	Unidentified plant	-------	2
B12527	N27x	do	Clay in shale	.7	-------
B12547	N39y	Park City	Lead concentrate	385	-------

ARIZONA

B13231	P1x	13 miles east of Jacobs Lake	Gray shale	1	-------
B13232	P1y	do	Ferruginous layer	11	-------
B13233	P12	do	Black mineral in shale	57	-------
B13234	P2	6 miles south of Vail	Soil, 0–6 inches	2	-------
B13236	P2a	do	Grasses	-------	2
B13237	P2b	do	Acacia	-------	1
B13240	P4x	Sonoita	Red sandstone	.4	-------
B13241	P4a	do	Plant growing on P4x	-------	0
B13258	P12	10 miles northeast of Douglas	Soil, 0–6 inches	.6	-------
B13259	P12a	do	Grass	-------	0
B13260	P13	do	Adobe soil, 0–6 inches	1	-------
B13263	P16x	Bisbee	Salt crust	13	-------
B13266	P19x	Clifton	do	1.5	-------

NEW MEXICO

B13749	Q12x	22 miles south of Almagorda	Gypsum sand	0.2	-------
B13750	Q13x	Las Vegas	Dark shale	1	-------
B13751	Q13y	do	Gypsum in shale	1	-------
B13752	Q14	9 miles east of Las Vegas	Soil over limestone	.2	-------
B13753	Q15x	1 mile north of Wagon Mound	Dark shale	.3	-------
B13754	Q15y	do	Ferruginous layer	.5	-------
B13755	Q16x	2 miles north of Wagon Mound	Alkali basin soil	.3	-------
B13756	Q17x	6 miles east of Springer	Shale	2.5	-------
B13757	Q17y	do	Gypsum layer	2.3	-------
B13760	Q20	6½ miles north of Maxwell	Salty soil, 0–6 inches	1	-------
B13741	Q5x	American Metal Mine	Copper concentrate	365	-------

THE BELLE FOURCHE IRRIGATION AREA OF SOUTH DAKOTA

The survey work was for a time seriously interrupted by the demand for an investigation of the Belle Fourche Irrigation Project. This area has been in active operation for nearly 25 years. While no alkali disease was known to occur in the area and no other indications of selenium poisoning were observed, yet because it was known to be on soils derived from Pierre shale and because it was proposed to greatly increase utilization of the project, it seemed urgent that an examination be made. The work was undertaken pursuant to a request by L. C. Gray, Chief of the Land Policy Division of the Agricultural Adjustment Administration. The preliminary inspection of the area was made by F. W. Hayes and the writer. The collection of samples for the most part was by Hayes. Very valuable assistance was rendered by C. S. Scofield and Beyer Aune, of the Division of Western Irrigation Agriculture, Bureau of Plant Industry.

Altogether some 600 samples of soil and vegetation were collected and examined for selenium and sulphur content, and several samples of water were also examined. A detailed report was made to Dr. Gray on November 9, 1934. The net results of the investigation were extremely valuable. In table 25 are given the results obtained from samples from a single township. In all the area the results were of the same order. Representative samples were obtained from 16 townships.

TABLE 25.—*Selenium content of samples of soil and vegetation from T. 8 N., R. 6 E., in the Belle Fourche Irrigation Project, Butte County, S. Dak.*

Laboratory no.	Field no.	Location	Material	Selenium in—	
				Soil or shale	Vegetation
				P. p. m.	*P. p. m.*
B10758	1	SE corner sec. 3	Pierre clay, 0–6 inches	0.7	
B10759	1a	do	Weed not identified		1
B10760	2	NE corner sec. 3	Pierre clay, 0–6 inches	.5	
B10761	2a	do	Alfalfa		0
B10762	3	NW corner sec. 3	Pierre clay, 0–6 inches	.7	
B10763	3a	do	Ragweed		0
B10764	4	SW corner sec. 3	Pierre clay, 0–6 inches	1	
B10765	4a	do	Corn (ear)		1
B10766	1	SE corner sec. 5	Pierre clay, 0–6 inches	.6	
B10767	1a	do	Sunflower		1
B10768	2	NE corner sec. 5	Pierre clay, 0–6 inches	.7	
B10769	2a	do	Ragweed		0
B10770	3	NW corner sec. 5	Pierre clay, 0–6 inches	.7	
B10771	3a	do	Wild aster		1
B10772	4	SW corner sec. 5	Pierre clay, 0–6 inches	1	
B10773	4a	do	*A. crassicuarpus*		110
B11507	1	SW corner sec. 11	Pierre clay, 0–6 inches	1	
B11508	1a	do	Russian-thistle		0
B10774	1	SE corner sec. 12	Pierre clay, 0–6 inches	.5	
B10775	1a	do	Wheatgrass and heads		0
B10776	2	NE corner sec. 12	Pierre clay, 0–6 inches	2	
B10777	2a	do	Ragweed		(1)
B10778	3	NW corner sec. 12	Pierre clay, 0–6 inches	1	
B10779	3a	do	Russian-thistle		0
B10780	4	SW corner sec. 12	Pierre clay, 0–6 inches	.5	
B10781	4a	do	Ragweed		1
B10401	1	SE corner sec. 16	Pierre clay, 0–6 inches	.5	
B10402	1a	do	Russian-thistle		0
B10403	2	NE corner sec. 16	Orman clay loam, 0–6 inches (mapped Pierre clay loam)	1	
B10404	2a	do	Alfalfa and seed		1
B10405	3	NW corner sec. 16	Pierre clay loam, 0–6 inches	.5	
B10406	3a	do	Russian-thistle		0
B10407	4	SW corner sec. 16	Pierre clay loam, 0–6 inches	.4	
B10408	4a	do	Sunflower		0
B10409	1	SE corner sec. 18	Vale loamy fine sand, 0–6 inches	.2	
B10410	1a	do	Corn (ear)		0
B10411	2	NE corner sec. 18	Pierre clay loam, 0–6 inches	.5	
B10412	2a	do	Corn (tassels and leaves)		1
B10413	3	NW corner sec. 18	Pierre clay loam, 0–6 inches	.5	
B10414	3a	do	Russian-thistle		(1)
B10415	4	SW corner sec. 18	Vale fine sandy loam, 0–6 inches	.3	
B10416	4a	do	Sunflower		0
B10417	4b	do	Corn		0
B10418	5	do	Pierre clay loam	.5	
B10419	5a	do	Sugar beets and tops		0
B10782	1	North of center sec. 23	Vale loam, 0–6 inches (mapped Pierre).	.4	
B10783	1a	do	Sunflower heads		0
B10784	2	NE corner sec. 23	Orman clay, 0–6 inches	.6	
B10785	2a	do	Wild aster		1
B10786	2b	do	Alfalfa		1
B10787	3	NW corner sec. 23	Vale gravelly sandy loam, 0–6 inches.	1	
B10788	3a	do	Russian-thistle		1
B10789	4	W¼ corner sec. 23	Pierre clay loam, 0–6 inches	.6	
B10790	4a	do	Alfalfa		0
B11509	1	SE corner sec. 26	Vale fine sandy loam, 0–6 inches	.5	
B11510	1a	do	Ragweed		(1)

[1] Trace.

TABLE 25.—*Selenium content of samples of soil and vegetation from T. 8 N., R. 6 E. in the Belle Fourche Irrigation Project, Butte County, S. Dak.*—Continued

Laboratory no.	Field no.	Location	Material	Selenium in—	
				Soil or shale	Vegetation
				P. p. m.	*P. p. m.*
B10791	1	SE corner sec. 29	Pierre clay loam, 0–6 inches	0.7	
B10792	1a	do	Wild aster		4
B10793	2	¼ mile north of NE corner sec. 29.	Vale very fine sandy loam, 0–6 inches (mapped Pierre clay loam).	.4	
B10794	2a	do	Corn (ear)		0
B10795	3	NW corner sec. 29	Laurel very fine sandy loam, 0–6 inches (mapped meadow)	1.5	
B10796	3a	do	Wild aster		1
B10797	4	SW corner sec. 29	Pierre clay loam, 0–6 inches	.7	
B10798	4a	do	Wild aster		1
B10799	4b	do	Sugar beet tops		2
B11511	1	SW corner sec. 30	Vale loam, 0–6 inches	.6	
B11512	1a	do	Wild aster		1
B10800	1	SE corner sec. 34	Vale fine sandy loam, 0–6 inches	.5	
B10801	1a	do	Sunflower heads		1
B10802	2	NE corner sec. 34	Vale fine sandy loam, 0–6 inches	.5	
B10803	2a	do	Sunflower heads		1
B10804	3	NW corner sec. 34	Pierre clay loam, 0–6 inches	.4	
B10805	3a	do	Ragweed		1
B10806	4	SW corner sec. 34	Pierre clay loam, 0–6 inches (very alkaline)	.7	
B10807	4a	do	Weed (not identified)		0

An inspection of the representative data reveals a number of interesting facts. All of the soil samples, whether of Pierre, Orman, Laurel, or Vale series, contain appreciable quantities of selenium, in some instances quite sufficient to produce toxic vegetation were one to judge by results obtained elsewhere. The quantities found in soils of the Vale series are usually smaller than in the other series. The Vale soil is presumably developed on outwash from the Black Hills and the parent material is only in part composed of shale. The plant material growing in the whole area is for the most part so low in selenium content as to be essentially innocuous. The exception is the species of *Astragulus* found in a few spots over the area. In all, about 10 such samples were found and yet, for *Astragulus*, the quantities of selenium which they contained were relatively low. The key to the apparent anomaly is furnished by the work of Hurd-Karrer (*10, 11, 12*) already referred to. Several soil profiles were examined for their content of available sulphur. Since in some portion of the profile of all the Pierre shale-derived soils there occur seams of gypsum, or accumulations of gypsum, it seemed inadvisable to compare total sulphur content with selenium content. A perfectly arbitrary comparison was therefore employed. The sections of the soil profiles were treated with fivefold the "saturation capacity" of water and an aliquot obtained by filtration through a Pasteur-Chamberland filter. This aliquot was examined for sulphur content and the total quantity in solution calculated back to terms of parts per million for the air-dry soil. The quantity of sulphur thus obtained is compared in table 26 with the total selenium in the soil. It is recognized that the values so obtained are but a rough approximation to the relative concentrations of the sulphur, as sulphate, and the selenium in the soil solution. It does not seem practicable to differentiate between soluble and nonsoluble selenium. In order

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to make comparison between conditions in the Belle Fourche area and elsewhere, 2 profiles were secured, 1 from Jones County, S. D., and 1 from Lyman County in which the sulphur-selenium ratio is low, at least in the upper portion of the profile.

TABLE 26.—*Selenium content of profile samples and comparison with sulphur content of soil solution from*

T. 9 N., R. 4 E., SEC. 14, ONE-FOURTH MILE SOUTH OF NORTH SECTION LINE ON EAST SIDE OF DITCH, NONIRRIGATED

Laboratory no.	Field no.	Material	Selenium in—		Soluble sulphur	Soluble HCO_3	Soluble Cl	Ratio S/Se
			Soil or shale	Vegetation				
			P.p.m.	*P.p.m.*	*P. p. m.*	*P.p.m.*	*P.p.m.*	
B11796A	1a	Sunflower heads		2				
B11796B	1b	Ragweed		2				
B11792	1	Orman clay, 0–12 inches	1		70			70
B11793	1	Orman clay, 12–26 inches	2.5		157	427	105	63
B11794	1	Orman clay, 26–39 inches	2.5		2,696	229	254	1,078
B11795	1	Orman clay, 39–50 inches	3		2,862	107	306	954
B11796	1	Orman clay, 50–60 inches	3		2,462	124	385	821

T. 9 N., R. 4 E., SEC. 14, ONE-FOURTH MILE SOUTH OF NORTH SECTION LINE ON WEST SIDE OF DITCH, IRRIGATED

B11801A	2a	Corn (ear)		0				
B11801B	1b	Sunflower heads		.5				
B11797	2	Orman clay, 0–12 inches	1.5		88	316	8	59
B11798	2	Orman clay, 12–26 inches	2		288	275	16	144
B11799	2	Orman clay, 25–39 inches	2		1,638	49	14	819
B11800	2	Orman clay, 39–50 inches	2		2,221	110	80	1,111
B11801	2	Orman clay, 50–60 inches	2.5		3,571	61	105	1,428

T. 9 N., R. 6 E., SEC. 18, ONE-FOURTH MILE NORTH AND ONE-FOURTH MILE WEST OF SOUTHEAST CORNER SEC. 18

B10342	8a	Buffalo grass		0				
B10341	8	Pierre clay, 0–12 inches	0.5		30.9	90	10	61
B10343	8x	Pierre clay, 12–39 inches	1		125.4	27		125
B10344	8y	Pierre clay, 43–58 inches	3		1,667	106	70	556

T. 9 N., R. 6 E., SEC. 18, ONE-FOURTH MILE NORTH AND ONE-FOURTH MILE WEST OF SOUTHEAST CORNER, 500 FEET EAST OF DRY PROFILE, IRRIGATED

B10346	9a	Alfalfa		0				
B10347	9b	Corn (ear)		0				
B10354	9	Pierre clay, 0–12 inches	0.5		193.7	256	210	387
B10348	9x	Pierre clay, 12–39 inches	1		968	179	68	968
B10349	9y	Pierre clay, 43–58 inches	2		2,470	166	71	1,235

T. 8 N., R. 7 E., SEC. 30, ONE-EIGHTH MILE WEST OF NORTH ONE-FOURTH CORNER

B11791	14a	Sunflower heads		1				
B11791A	14b	Ragweed		0				
B11786	14	Vale fine sandy loam, 0–10 inches	0.2		89	158	7	450
B11787	14	Vale fine sandy loam, 10–24 inches	.2		55	122	6	275
B11788	14	Vale fine sandy loam, 24–35 inches	.3		65	97	5	217
B11789	14	Vale fine sandy loam, 35–46 inches	.4		89	97	5	222
B11790	14	Vale fine sandy loam, 46–60 inches	.5		170	158	5	340

TABLE 26.—*Selenium content of profile samples and comparison with sulphur content of soil solution from*—Continued

T. 9 N., R. 4 E., SEC. 36, NORTHWEST ONE-FOURTH CORNER

Laboratory no.	Field no.	Material	Selenium in—		Soluble sulphur	Soluble HCO_3	Soluble Cl	Ratio S/Se
			Soil or shale	Vegetation				
			P. p. m.	*P. p. m.*	*P. p. m.*	*P. p. m.*	*P. p. m.*	
B10333	5	Wild lettuce		30				
B10334	6	Alfalfa		2				
B10335	7	Orman clay, 0–2 inches	1.5		39	259	148	26
B10336	7w	Orman clay, 2–9 inches	1.5		112	244	192	75
B10337	7x	Orman clay, 9–18 inches	7		1,844	198	87	263
B10339	7y	Orman clay, 18–36 inches	9		3,220	122	1,180	358
B10340	7z	Orman clay, 36–50 inches	4		1,796	213	612	449
B10338	7xx	Orman clay, 50–62 inches	4		1,588	106	165	397

T. 9 N., R. 6 E., SEC. 20, ONE-FOURTH MILE EAST AND 600 FEET SOUTH OF NORTHWEST CORNER

B11802A	1a	Saltgrass		0				
B11802B	1b	Ragweed		0				
B11802C	1c	Salt bush		(1)				
B11802	1	Pierre clay, 0–⅛ inch (white crystals).	1		30,921	219	4,410	30,921
B11803	1	Pierre clay, ⅛–2 inches	.7		7,002	192	5,267	10,003
B11804	1	Pierre clay, 2–9 inches	1		3,226	97	2,240	3,226
B11805	1	Pierre clay, 9–18 inches	1.5		3,794	195	2,170	2,529
B11806	1	Pierre clay, 18–36 inches	1.5		3,379	146	1,750	2,253
B11807	1	Pierre clay, 36–50 inches	1.5		3,973	122	787	2,649
B11808	1	Pierre clay, 50–72 inches	1.5		3,572	152	1,662	2,381

T. 2 N., R. 30 E., SEC. 35, JONES COUNTY

B9195	3a	Russian-thistle		1				
B12089	3	Boyd clay loam, 0–12 inches	2.5		1.6	256	7	0.6
B12040	3	Boyd clay loam, 12–24 inches	4		954	158	14	238
B12091	3	Boyd clay loam, 24–36 inches	4		1,395	145	35	249
B12092	3	Boyd clay loam, 36–48 inches	3		1,698	130	35	566
B12093	3	Boyd clay loam, 48–60 inches	3.5		1,815	122	30	519
B12094	3	Boyd clay loam, 60 inches, +	3.5					

T. 108 N., R. 78 W., LYMAN COUNTY

B8155	24a	Mixed grasses		10				
B12095	21b	Wild aster		2,130				
B12096	24c	Gumweed		905				
B12097	24d	Russian-thistle		50				
B12098	24	Boyd clay loam, 0–8 inches	3.5		7	488	30	2.0
B12099	24	Boyd clay loam, 8–12 inches	4		2	396	26	.5
B12100	24	Boyd clay loam, 12–24 inches	5		1.5	385	115	.3
B12101	24	Boyd clay loam, 24–36 inches	6		70	390	126	12
B12102	24	Boyd clay loam, 36–48 inches	8		1,860	146	285	232
B12103	24	Boyd clay loam, 48–60 inches	12		1,868	170	323	156

[1] Trace.

An examination of the data in table 26 will make clear that in all cases where the sulphur-selenium ratio is high—50 or more—the selenium content of the vegetation is low. In the profile of Orman clay in sec. 36, T. 9 N., R. 4 E., in which the surface soil is high in selenium and low in sulphur, a sample of wild lettuce has a serious quantity of selenium. Whether this is because wild lettuce fails to respond to the inhibiting effect of sulphur or because it, like wild aster, certain species of *Astragulus*, and a number of other plants, has a special tendency to absorb selenium, cannot be determined, since this sample of wild lettuce is the only one so far examined. The

most instructive profiles in this table are those from Jones and Lyman Counties. The profile from Jones County was sought because it had been observed that in the part of the county where this sample was taken the samples of vegetation were relatively low. The one from Lyman County was sought because in section 36 the vegetation ran unusually high. It will be observed that while the sulphur-selenium ratio is low in the 0–12-inch layer of the Jones County sample, it becomes very high at lower levels. In the Lyman County profile, on the other hand, the sulphur-selenium ratio remains low to below the 3-foot level.

Since it is clear that no serious selenization of the vegetation in the Belle Fourche area exists at present, the question arises as to the future. In this project the irrigation method employed was the surface type with no special provision for underdrainage ditches. In a gumbo soil the inevitable result was increased salinity of the surface soil and the development of alkaline seeps. Recently drainage ditches have been dug and the effort is being made to provide tile underdrains. These, under normal conditions, should result in decreased salinity and a probable alteration in the sulphur-selenium ratio. Fortunately there exists a tile drain on the experimental farm which has been in operation for 18 years and one which has operated for 1 year only. Samples of the irrigation water and of the effluent from the two drains were secured and examined. The results are given in table 27.

TABLE 27.—*Selenium content of water samples from the Belle Fourche area, S. Dak.*

[Sent in by Beyer Aune]

Laboratory no.	Field no.	Sample	Selenium	Sulphur	Carbonate	Chlorine	Total solids
			P. p. m.	*P. p. m.*	*P. p. m.*	*P. p. m.*	*P. p. m.*
B11723	3	Water from Government town-site lateral, representing irrigation water	0.00	293	116	28	1,488
B11721	1	Drainage water from tile drain installed in 1916, SE ¼ of SE ¼ sec. 24, T. 9 N., R. 5 E., field A, plots 1–7	.08	1,148	458	78	5,930
B11722	2	Drainage water from tile drain installed in 1933, SE ¼ of SE ¼ of sec. 13, T. 9 N., R. 5 E., field 0	1.2	3,662	915	3,133	32,250

It will be observed that the irrigation water is abnormally rich in soluble sulphates and contains no selenium. The drainage water of the new tile drain, sample no. 2, contains a very large quantity of selenium and the drain is obviously removing both selenium and other saline material from the soil. The old drain probably represents an approach to equilibrium between soil and drainage so far as ordinary saline material is concerned, but removal of selenium is continuing. The tentative conclusion is therefore drawn that no probable danger from selenium exists now in this area or will exist in the future. This conclusion obviously assumes that the introduction or spread of vegetation with special power of selenium absorption is not permitted and that good drainage is maintained.

SPECIAL ITEMS

In connection with the field operations designed to determine the extent of the area involved in the selenium problem a number of items more or less incidental to the program come up for consideration. One of these of special importance concerns the fate of the selenium

of ingested foods. Some light is thrown on it, however, by the field data collected. Vegetation normally consumed locally, such as garden vegetation, or fed to animals which are consumed at home or products of which are used for food, may well constitute so large a portion of the diet as to be toxic. In general, garden vegetation in the area examined was almost impossible to obtain by reason of the drought. Table 28 contains a group of miscellaneous observations on milk, eggs, and vegetables. The eggs of samples B10670 and B10670a were from chickens fed grain of the selenium content shown by samples B10671, B10672, and B10673. These facts, together with the fact, derived from unpublished data, that selenium appears in every tissue of selenium-fed animals, obviously bring the problem into the domain of public health. It becomes of importance, therefore, to devise methods of diagnosis and detection of incipient selenium poisoning. A step in this direction has been made and some data furnished by Dudley and Byers (*4*).

TABLE 28.—*Selenium content of miscellaneous samples of eggs, milk, and vegetables from the selenized areas*

Laboratory no.	Field no.	Location	Material	Selenium
				P. p. m.
B7856	-------	Sec. 28, T. 3 N., R. 31 E	Whole milk	1.2
B7856	-------	----do	Milk solids	9.6
B11814	-------	Sec. 34, T. 107 N., R. 78 W	Milk	.5
B10724	29a	----do	Corn	----------
B10744	42a	----do	----do	----------
B10400	x6	Sec. 17, T. 95 N., R. 65 W	Milk	.3
B13766	-------		Milk from a cow fed inorganic selenium.	2
B11813	-------	Sec. 10, T. 1 N., R. 30 E	Egg white	6
B11,813	-------	----do	Egg yolk	1
B11,813	-------	----do	Egg shell	3
B11813	-------	Sec. 20, T. 107 N., R. 78 W	Whole egg	10
B10670	-------	Sec. 2, T. 106 N., R. 78 W	Egg white and shell	9
B10670a	-------	----do	Egg yolk	7
B10671	Z1	----do	Corn (from crib)	3
B10672	Z2	----do	Wheat (from granary)	5
B10673	Z3	----do	Rye (from granary	5
B10530D	x12	Randall Creek	Turnip leaves	25
B10529A	x9	Sec. 17, T. 95 N., R. 65 W	String beans	2
B11810	3b	Sec. 18, T. 106 N., R. 76 W	Lettuce	7
B11812	3d	----do	Cabbage	100

One of the most interesting portions of this investigation concerns the area in Randall Creek Valley, Gregory County, S. Dak. In the introduction mention was made of the outbreak of a "very fatal" new disease among the cavalry horses at Fort Randall in 1856. As soon as this information had been called to the writer's attention by Dr. Franke, Hayes was requested to locate Fort Randall and the east side of a "dry ravine" described by Dr. Madison as the probable source of the trouble and also to obtain samples of soil and vegetation. This was done and a sketch map of the area prepared (fig. 4). The samples were examined and the results are presented in table 29. It will be seen that the vegetation samples above the line running west from the fort are the most toxic in the area although all samples show the presence of selenium. At the head of the dry ravine are a number of low hills and tradition has it that the Indians were in the habit of hiding behind these hills and watching for an opportunity of stampeding the horses across the ravine. This doubtless caused the establishment of an observation post just north of the ravine-road crossing. This point commands a view of the ravine for a long dis-

tance. The animals were therefore pastured in the area northwest of the fort. If this assumption is correct then it becomes obvious that the area toxic in 1856 is still toxic in 1934. In any case the data furnish a convincing bit of evidence that selenium is the real cause of

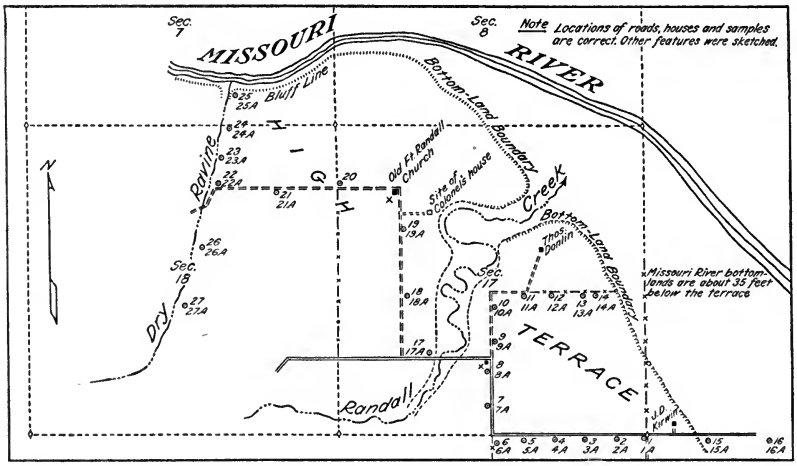

FIGURE 4.—Sketch map of Randall Creek area, Gregory County, S. Dak. Transect through old Fort Randall military post T. 95 N., R. 65 W. Scale 4 inches=1 mile.

alkali disease. Evidence of this fact is, however, overwhelming from independent sources.

TABLE 29.—*Selenium content of soil and vegetation from T. 95 N., R. 65 W., Fort Randall, S. Dak.*

Laboratory no.	Field no.	Material	Selenium in—	
			Soil	Vegetation
			P.p.m.	*P.p.m.*
B4893	1	Terrace soil	2.5	-------
B4866	1a	Green Russian-thistle	-------	15
B4894	2	Terrace soil	2.5	-------
B4867	2a	Green Russian-thistle	-------	20
B4895	3	Terrace soil	2	-------
B4868	3a	Green Russian-thistle	-------	4
B4896	4	Terrace soil	2	-------
B4869	4a	Young barley	-------	2
B4897	5	Terrace soil	2	-------
B4870	5a	Young barley	-------	2
B4898	6	Colluvial slope	1.5	-------
B4871	6a	Young barley	-------	5
B4899	7	Terrace soil	1.5	-------
B4872	7a	Young wild aster	-------	15
B4900	8	Terrace soil	1.5	-------
B4873	8a	Young wild aster	-------	25
B4901	9	Terrace soil	2	-------
B4874	9a	Western wheat-grass	-------	5
B4902	10	Terrace soil	1	-------
B4875	10a	Young wheat	-------	6
B4903	11	Terrace soil	2	-------
B4876	11a	Young wheat	-------	4
B4904	12	Terrace soil	1	-------
B4877	12a	Young wheat	-------	2
B4905	13	Terrace soil	1	-------
B4878	13a	Young wheat	-------	8
B4906	14	Terrace soil	0.7	-------
B4879	14a	Lambsquarters	-------	8
B4907	15	Soil in Missouri bottom	1.5	-------
B4980	15a	Lamsquarters	-------	2
B4908	16	Soil in Missouri bottom	2.5	-------
B4981	16a	Young wild aster	-------	560
B4909	17	Terrace soil	3.0	-------
B4982	17a	Lambsquarters	-------	15
B4910	18	Terrace soil	.7	-------
B4983	18a	Sunflower	-------	7
B4911	19	Terrace soil	.7	-------
B4944	19a	Lambsquarters	-------	(1)
B4912	20	Terrace soil	.5	-------
B4913	21	---- do	.5	-------
B4986	21a	Young barley	-------	1
B4914	22	Terrace soil	.7	-------
B4987	22a	Grass	-------	50
B4915	23	Terrace soil	.7	-------
B4988	23a	Black grama grass	-------	4
B4916	24	Terrace soil	.4	-------
B4989	24a	Black grama grass	-------	(1)
B4917	25	Terrace soil	.3	-------
B4990	25a	Black grama grass	-------	(1)
B4918	26	Terrace soil	.5	-------
B4991	26a	Grass	-------	50
B4919	27	Boyd silt loam	1	-------
B4992	27a	Russian-thistle	-------	40

[1] None.

A third special item of considerable interest is shown by the data of table 30. These samples were secured by Hayes at the request of W. J. Sutton, the owner of the ranch in question. The summer of 1934 was so dry that pasturage was limited and animals were forced to eat whatever vegetation was available. It seems evident, therefore, that Mr. Sutton was quite correct in his view that he was having abnormal losses and that his chief source of trouble is in the neighborhood of field no. 2 in section 28. This is the highest selenium content so far found in any soil.

TABLE 30.—*Selenium content of soils and vegetation from T. 98 N., R. 69 W., the W. J. Sutton ranch, Gregory County, S. Dak.*

Laboratory no.	Field no.	Location	Material	Selenium in—	
				Soil	Vegetation
				P.p.m.	*P.p.m.*
B6486		Sec. 32	Boyd clay loam	0.8	
B6487	1a	do	Wild aster		13
B6490	3	do	Boyd clay loam	1	
B6491	3a	do	Shoestring		0
B6506	11	do	Shaly Boyd clay loam	5	
B6507	11a	do	Rosinweed		7
B6488	2	Sec. 28	Soil, alkali (supposed source of trouble)	41	
B6489	2a	do	Lambsquarters		2
B6515		do	Gypsum shale	21	
B6500	8	Sec. 29	Boyd clay loam	3	
B6501	8a	do	Shoestring		7
B6502	9	do	Shaly Boyd clay loam	.8	
B6503	9a	do	Shoestring		1
B6504	10	do	Boyd clay loam	3	
B6505	10a	do	Wild aster		60
B6508	12	Sec. 30	Boyd clay loam	.3	
B6509	12a	do	Shoestring		.5
B6510	13	do	Shaly Boyd clay loam	.4	
B6511	13a	do	Sunflower		.5
B6512	14	do	Boyd clay loam	14	
B6513	14a	do	Yucca pods		1
B6514	14b	do	Shoestring		2
B6492	4	Sec. 33	Boyd clay loam	3.5	
B6493	4a	do	Plant not identified		2
B6494	5	do	Boyd clay loam		
B6495	5a	do	Lambsquarters		8
B6496	6	do	Boyd clay loam	.8	
B6497	6a	do	Not named		2
B6498	7	do	Boyd clay loam	.6	
B6499	7a	do	Shoestring		0

GENERAL DISCUSSION

Considering the selenium problem as a whole in the light of the data assembled herein and of unpublished data in the files of the department, a number of definite conclusions may be reached and certain valid inferences may be drawn. It seems perfectly clear that the ultimate source of selenium in the soils is in the pyrite or similar minerals occurring in the geological formations which, through weathering, produce soils. It obviously follows that if a parent material contains no selenium the soils contain none. It also seems perfectly clear that when soils are produced with a rainfall sufficient to produce leaching through the soil profile selenium can be present in the soil only in traces. It seems quite probable that no sandy soils exist which contain selenium in notable quantities, both by reason of lower original content of seleniferous minerals and more complete leaching than is the case with heavy clay soils. If these observations are valid it then follows that seleniferous soil areas may be expected

in all arid and semiarid areas where the soils are derived from selenium-bearing strata. It would seem probable, therefore, that seleniferous soils are to be found in certain portions of the chernozem soil areas which are the great wheat-producing areas of the world. There are definite indications that such seleniferous areas actually exist in four continents, at least.

When selenium exists in the soil it will appear in all vegetation growing upon the soil. The quantity so found appears to vary with (1) the concentration in the soil; (2) the composition of the soil especially with respect to available sulphur; (3) the kind of vegetation; (4) the stage of growth of the vegetation; (5) the portion of the plant examined. In general it would appear that any soil containing upwards of 0.5 p.p.m. of selenium, and any vegetation containing 5 p.p.m. is potentially dangerous. In the latter case, of course, the possibility of injury to the consumer decreases as the fraction of seleniferous matter in the total diet decreases.

It seems perfectly clear that selenium, when present in food, finds its way into all the body tissues and is present in all secretions and excretions. It would seem to follow that selenium poisoning is not permanently cumulative, even though the injury to the tissues be, as apparently is the case, permanent in character.

The total area of soils demonstrated to contain selenium is enormous. It does not follow that all areas so affected produce toxic materials. Indeed, in the large single area closely examined there is not adequate evidence to show that all the vegetation produced, even on 1 square mile, is toxic in character. There is abundant evidence to indicate that certain areas produce little or no toxic vegetation even where considerable quantities of selenium occur in the soils. Indeed, it seems probable that effective limitation of selenium absorption by vegetation through adequate soil treatment with sulphates is possible (*10*, *11*, *12*). Whether such remedial measures are economically practical has not as yet been demonstrated.

Certain plant species show relatively slight absorptive capacity for selenium. Notable among these are native prairie grasses. Other plant species show a marked tendency toward ready absorption. Among these appear to be species of legumes and compositae. The more common cereals are apparently of intermediate character.

The injury inflicted through seleniferous vegetation is most serious as a range poison and in some districts this injury has effectively prevented profitable use of lands for grazing. In other areas it would appear to be a serious handicap to profitable stock raising and to general farming operations. It would seem probable that in the more seriously affected areas were the local population accustomed to providing a considerable fraction of their diet from their own products, human injury would be extensive. In general, this is not the case, and in consequence definite evidence of human injury has been scanty. It seems probable that much injury has been inflicted, especially upon children, without the causes being recognized. Since diagnostic indications of mild injury have not been available this is not surprising.

Outside the affected area the danger to public health seems relatively slight since commercial crops are usually low in selenium as compared with certain perennial types of vegetation. Even where wheat of toxic types is marketed, as is sometimes the case, its dilution with

nontoxic wheat and the small fraction which bread constitutes of the total normal diet would tend to render it practically innocuous.

Experimental observations, not here recorded, show that where actually lethal vegetation does not occur, animals soon learn to avoid seleniferous vegetation. Even pigs avoid foods containing very slight contamination with inorganic selenium compounds. An examination of the analytical data reveals, as has been mentioned, the fact that as a rule native forage crops, buffalo grass, grama grass, bluestem, and needlegrass contain relatively very small quantities of selenium. These two facts render it probable that stock raising in seleniferous areas is practicable provided the ranges be not overgrazed. Indeed, the history of the known areas would seem to confirm this inference.

A very important phase of the investigation remains to be considered. The whole period during which the problem has been studied has been one of excessive dryness. In the summer of 1934 the great drought very seriously interfered with securing any vegetation in many cases. No one knows what conditions will arise during seasons of normal or excessive rainfall. It is undoubtedly the case that in a considerable portion of the affected area the selenium content of the vegetation will be lowered, since the sulphate layer of the soil is so near the surface. In others it may be greater. No satisfactory evidence either way is available through field inquiry. It is idle to speculate. We must await experimental data.

SUMMARY AND CONCLUSIONS

The existence of soil areas of enormous extent which contain selenium has been demonstrated and it has been shown that this material, when transferred to vegetation, is responsible for the illness and death of many animals. It is believed that further investigation will show wider extension of the affected areas. Areas of some extent are known to exist in several States.

The source of selenium in soils has been shown to be sulphide minerals occurring in the soil parent materials. So far as yet known the seleniferous soil-forming material is, for the most part, shales of the Cretaceous period. Soils derived from these shales, or from other seleniferous materials, may retain sufficient selenium to produce toxic vegetation when the mean annual rainfall is insufficient to produce percolation through the soil profile.

The distribution of the selenium is not uniform in any area examined, either in the surface soils or in the soil profile. There are indications of a zone of selenium concentration in the soil profile, either within or close to the zone of sulphate accumulation. The limits of no single area are accurately known but there is evidence warranting the belief that the effective distribution coincides with the distribution of certain soil series.

The amount of selenium absorbed from seleniferous soils by plants is apparently dependent on (1) the quantity of selenium and its distribution in the soil profile; (2) the kind of plant; (3) the portion of the plant examined; and (4) the soil composition, especially its available sulphur content. It is also believed that variation will also result from seasonal variation in rainfall.

On the basis of available data, both published and unpublished, the writer ventures the following considered suggestions: Any action based

upon the existing conditions should be carefully thought out. The areas of toxic arable land so far examined are close to or within areas otherwise submarginal, and it would seem wise to withdraw such seleniferous lands from cereal production, by purchase or otherwise. Grazing lands may safely be left to the discretion of the owners, as in the past. Irrigation areas should be carefully examined and controlled as conditions warrant. The study of toxic limits, tolerance limits, diagnostic symptoms, and remedial measures should be undertaken.

Tolerance limits should be set up as soon as possible, but the emergency, as shown by available data, is not serious enough to warrant hasty measures. Methods of analysis should be studied carefully to secure accurate control work at lessened cost. The exact extent of affected areas should be determined and remedial measures applicable to field conditions should be sought. Above all, the proper safeguarding of public health within the areas affected should be studied.

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TECHNICAL BULLETIN No. 481 July 1935

ORGANIZATION AND MANAGEMENT OF APIARIES PRODUCING EXTRACTED HONEY IN THE WHITE CLOVER REGION

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WASHINGTON, D.C.

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(The Bureau of Agricultural Economics and the Bureau of Entomology and Plant Quarantine in cooperation with the State College of Agriculture and the Agricultural Experiment Station at Cornell University, the College of Agriculture and the Agricultural Experiment Stations of the Universities of Wisconsin and Minnesota, the State Colleges of Agriculture of Michigan and Iowa, and Ohio State University)

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INTRODUCTION

The white clover region is the source of a large proportion of the honey produced in the United States and honey from this region ranks with the best on the market. Beekeeping there is conducted under a variety of different natural and economic conditions. Each situation has its effect on the practice employed in the care of bees and on the organization of the operating unit. Consequently, a rather wide variation occurs in apiary practice and business organization among beekeepers in this region.

During the 1930 and 1931 seasons records were kept by a selected group of commercial beekeepers producing extracted honey, of the daily labor expended on the beekeeping enterprise, the expenses incurred in the production of extracted honey, and the quantity of

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honey produced. In addition, inventories were taken of bees, buildings, and equipment. Periodic visits were made to check the records and general notes were recorded about each apiary. Both comb and extracted honey are produced and much of the product, particularly from the smaller apiaries, is sold locally in small lots through retail stores or direct to the consumer. But this detailed study does not include the records of comb-honey producers and no attempt was made to include data on the methods and costs of marketing retail honey or the influence of the different factors on income. In any given apiary the influence of a favorable factor, such as a low labor cost, may be entirely overshadowed by a low yield due to influences over which the beekeeper has little control, so that the influence on income of a favorable factor may be partially or wholly offset by unfavorable factors in the same apiary.

In the discussion that follows, the objective is to show the organization of the extracted honey business in a number of apiaries in the region and the cost of producing extracted honey, and to tra e the variation from apiary to apiary of some of the factors relative to economy and efficiency in the production of extracted honey. In describing the organization and management of some of the apiaries represented, it is not intended necessarily to recommend the equipment in use and the practices employed. It is assumed that the reader is familiar with the usual beekeeping terms and the general phases of beekeeping.

The number of apiaries included in the various tables is dependent on the data to be shown. Certain apiaries have been omitted from some of the tables because incomplete data or other irregularities render them incomparable with others included in the study. The term "apiary" as used in this bulletin refers to the total number of colonies of bees under the management of each beekeeper. The term "outyard" refers to a site at a distance from the home yard where a given number of colonies of bees are located. The distribution of these beekeepers and the number of colonies of bees represented are shown in table 1.

TABLE 1.—*Number of beekeepers and colonies of bees represented, 1930–31*

State	Beekeepers		Colonies of bees		State	Beekeepers		Colonies of bees	
	1930	1931	1930	1931		1930	1931	1930	1931
	Number	*Number*	*Number*	*Number*		*Number*	*Number*	*Number*	*Number*
New York	7	2	2,993	844	Iowa	9	7	725	471
Michigan	6	5	2,360	2,236	Minnesota	8	8	1,963	2,495
Ohio	8	6	3,263	1,779					
Wisconsin	2		358		Total	40	28	11,662	7,825

PRINCIPAL HONEY PLANTS IN THE WHITE CLOVER REGION

White clover is widely distributed throughout the United States except in the arid regions. In the area comprising the northeastern portion of the United States, extending westward to Minnesota and south approximately to the Ohio River and the Mason and Dixon Line, white clover reaches its greatest importance as a nectar-producing plant. Where soil and climatic conditions are favorable, this plant produces large honey surpluses. But honey producers in this

region are not dependent entirely on white clover, for alsike clover in some localities is more important than white clover and the honey produced from it is equal in quality to that from white clover. Formerly these clovers were the main honey plants in the region, but during recent years sweetclover has become an important nectar-producing plant in many parts. Some of the beekeepers consider that more of their honey is now obtained from sweetclover than from white or alsike clover. This was particularly true in both 1930 and 1931 when, because of the prolonged drought, white and alsike clover were more severely damaged than was the more drought-resistant sweetclover. White and alsike clovers, however, are at the present time the most important honey plants in years of normal rainfall.

The honey flow from sweetclover in favorable seasons, especially in certain sections of Minnesota, extends over a period of nearly 2 months and comes on somewhat later than in the case of white or alsike clovers. This gives a long period in which to build up the colonies for the honey flow, enabling even divided colonies or package bees to be built up to sufficient strength during the white and alsike clover honey flow to gather a surplus from sweetclover. On the other hand, in an exclusively white clover area, a full crop of honey may be expected only from colonies and package bees that have reached the peak of population previous to the blooming period of white and alsike clover.

Although with most beekeepers the heaviest honey flow of the season comes from the clovers, other honey plants are important in local areas. Buckwheat is an important source of honey on soils that are derived from sandstone and shales in parts of Pennsylvania and New York; the honey flow from this plant usually occurs during August and early September. In parts of Michigan and Minnesota wild raspberry, milkweed, and fireweed produce a surplus crop in favorable seasons. Basswood, maples, dandelion, fruit bloom, goldenrod, asters, heartsease, and Spanish needle form important sources in many parts of the region.

Dates and duration of the honey flow vary according to the location and the nature of the available honey plants. The average blooming dates and the duration of the honey flow for the principal honey plants in the region are shown in figure 1.

APIARY ORGANIZATION

There are many large apiaries in the white clover region, but those of small-to-medium size predominate. The business organization of the small unit is relatively simple. The operator does most, if not all, the work himself. Few outyards are required and in many instances no special buildings are needed. On the other hand, the large apiary requires hired labor, more equipment, and a systematic arrangement of outyards to form an economically operated business unit.

SIZE OF APIARY AND CAPITALIZATION

The capital distribution of apiaries of different sizes based on inventory values as of 1930 is shown in table 2. Of the 40 beekeepers represented, 9 operated less than 100 colonies, 15 were handling from 100 to 299 colonies, and 16 had 300 or more colonies.

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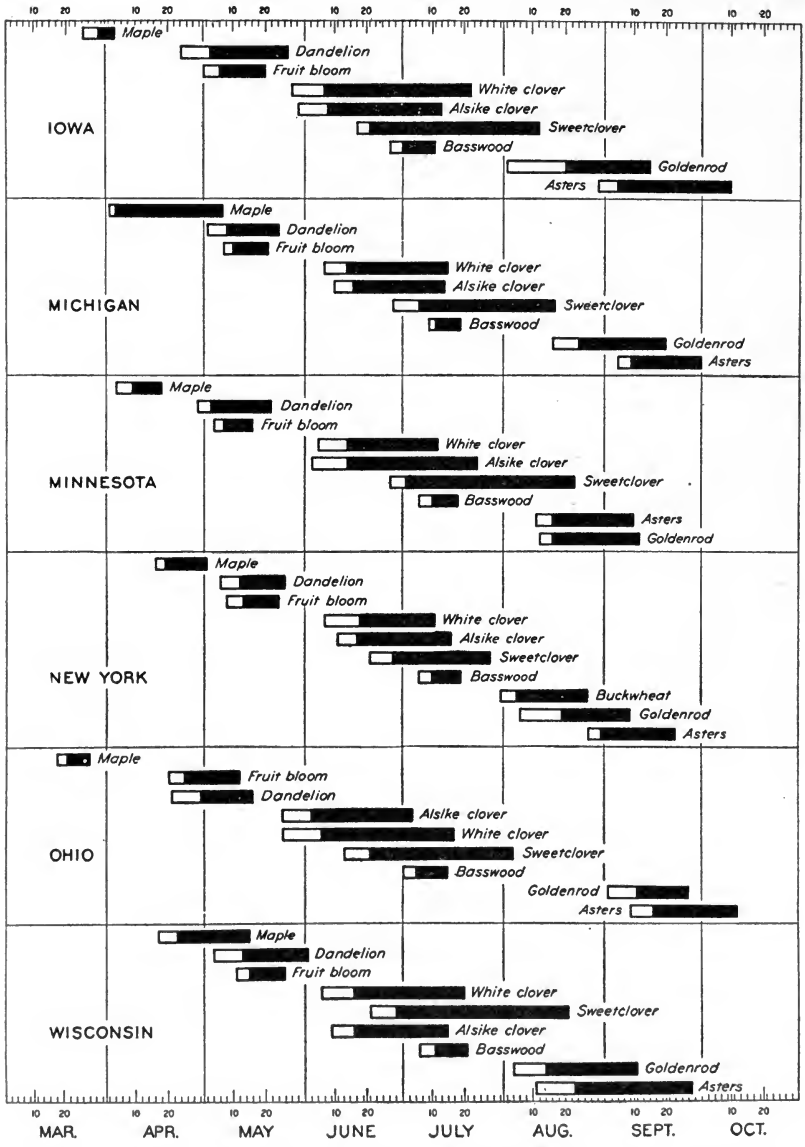

FIGURE 1.—BLOOMING DATES AND PERIOD OF NECTAR FLOW FOR THE PRINCIPAL HONEY PLANTS IN THE WHITE CLOVER REGION. (AVERAGES FOR YEARS 1926–32, INCLUSIVE.)

The clovers are the main honey plants in this region. The nectar secreted from this source is supplemented by that from maples, fruit bloom, and dandelion in the early spring and from asters and goldenrod after the main flow. Many other minor sources of nectar appear throughout the season. (The clear portion of each bar represents the period that the plant was in bloom before the nectar flow. The black portion represents the length of the honey flow for that plant.)

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TABLE 2.—*Average capital distribution for apiaries of different sizes, Jan. 1, 1930* [1] [2]

Size of apiary (colonies)	Apiaries studied	Average colonies per apiary	Average capital per apiary					Average capital per colony
			Bees [3]	Buildings	Permanent equipment	Supplies	Total	
	Number	*Number*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*
Less than 100	9	49	383	196	608	4	1,191	24.31
100 to 299	15	178	1,433	545	1,435	14	3,427	19.25
300 to 499	8	396	3,301	849	3,405	16	7,571	19.12
500 to 699	4	595	5,739	1,675	3,547	126	11,087	18.63
Over 700	4	850	6,749	2,105	5,777	142	14,773	17.38
Total or average	40	302	2,533	796	2,288	36	5,653	18.74

[1] The total number of colonies cared for by each beekeeper is here considered as 1 apiary, even though kept in more than 1 bee yard.

[2] No value is shown for land occupied by bee yards since the area occupied by each yard is relatively small and many times on waste land, along fence rows or in an orchard. The number of colonies per apiary is the number prepared for wintering in the fall of 1929. Subsequent tables show the numbers of colonies for the honey flow.

[3] Includes a complete 1-story hive, including bees and brood combs for each colony.

The number of colonies per beekeeper ranged from 25 in an apiary operated at spare times to 870 colonies in an apiary divided into 16 outyards. The number of colonies of bees located at each outyard depends on the amount and quality of the available bee pasturage and for the 40 beekeepers here represented varied from 16 to 150 colonies per yard. In the group having less than 100 colonies only two beekeepers had outyards and these were located in close proximity to the home yard. In the group having from 100 to 299 colonies approximately two-thirds of the beekeepers maintained from 1 to 6 outyards which ranged in size from 16 to 125 colonies per yard. The distance of these outyards from the home yard was from 2 to 32 miles. In the group having from 300 to 499 colonies the number of outyards varied from 1 to 13 and the distance from the home yard was from 1½ to 18 miles. The beekeeper with 13 outyards had 464 colonies of bees. In the group with 500 and more colonies the number of outyards varied from 4 to 16 and the distance from the home yard was from 1½ to 25 miles.

When beekeeping is part of a farm business and the number of colonies of bees is not large, special buildings are not often required. The honey-handling facilities are set up in some existing building. But even with a building especially erected for a honey house the capital represented by buildings for the small beekeeper is not large. Of the beekeepers with less than 100 colonies, only 1 had buildings valued at over $275. The average for the others was $158 per apiary. On the other hand, a special honey house which contains an extracting room and storage room for honey and supplies is usually provided in the larger units, and in many cases represents an appreciable capitalization. For beekeepers with 100 or more colonies, the inventory value of buildings varied from $175 for a beekeeper with 104 colonies to $4,320 for a beekeeper with 660 colonies. The latter has a honey house which is thoroughly modern and conveniently arranged for the handling of honey but probably represents a rather larger building capitalization than is necessary.

Permanent equipment including hive bodies, supers, extractors, etc., represents the largest item of capital for most apiaries. The

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range was from approximately $148 for a beekeeper with 36 colonies to $7,763 for an operator with 900 colonies. The majority of the beekeepers whose records are included in this study used queen excluders and inner covers and had two or more extracting supers per colony. In the group having less than 100 colonies, only 3 beekeepers used an automobile or truck and only one 45-frame radial extractor was represented. One 4-frame extractor was in use, and the remainder were 2-frame extractors. In the group with 100 or more colonies, an automobile or truck, or both, was in use by all except 2 beekeepers. Where the extracting was done at a central plant, which was the usual practice except in New York, the 45-frame radial extractor was the usual type. A number of these beekeepers also had smaller extractors, ranging in size from 2 to 8 frames. No doubt many of these smaller extractors were in use before the 45-frame radial extractor was installed. In New York, where the extracting was done at the outyard, the extractors ranged from 2 to 8 frames. Thirteen of the larger beekeepers use vertical steam boilers to furnish the steam supply. Where a considerable supply of steam is needed, as in a large central extracting plant such a boiler has many advantages. It supplies steam to heat the honey when necessary, to melt cappings, to heat the uncapping knife, to warm the honey house in cold weather and for other general uses. A number of the smaller beekeepers use either 2- or 5-gallon boilers to supply steam for an uncapping knife. Twenty-two of the larger extracting plants were equipped with electric motors and six used gasoline engines. Several of these plants were equipped with pulley shafts.

The average total capital per colony was greatest for the group having less than 100 colonies. This high average of $24 per colony, however, was largely due to one beekeeper who was equipped to handle many more colonies than those kept during the 1930 season. This particular beekeeper had inventory values of $58 per colony whereas the other beekeepers in this group had an average capitalization of slightly less than $20 per colony. The range in capitalization per colony for the group with 100 or more colonies per apiary was from approximately $15 to $30 per colony. The average for all apiaries was $18.74 per colony. The total capital per colony tended to be smaller on large than on small apiaries. A complete one-story hive, including bees and brood combs for each colony, represented about 45 percent; buildings, about 14 percent; permanent equipment, about 40 percent; and supplies, about 1 percent of the total capitalization.

Since depreciation, repairs, and interest on honey houses and equipment constitute a sizable item of expense, it is essential to have, as far as possible, the proper balance between buildings and equipment for the number of colonies kept. In some instances the inventory value of buildings appeared greater than the number of colonies warranted, and a large extractor or other large equipment apparently was not always justified by the number of colonies of bees handled. On the other hand, some beekeepers had too little equipment for the work to be done.

SUGGESTED EQUIPMENT FOR APIARIES OF DIFFERENT SIZES

The type of beekeeping equipment is to a large extent a matter of personal choice. Some of the beekeepers had accumulated equipment that was not of standard size and not readily interchangeable

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while others had equipment inventories that were too large for the number of colonies kept. Both of these conditions are contributing factors to the high cost of producing honey.

The equipment that appears to be adequate for the effective operation of apiaries of different sizes producing extracted honey is shown in table 3. These items are for a small, a medium-size, and a large apiary and are based largely on the equipment actually found in a number of well-organized apiaries.

TABLE 3.—*Principal items of equipment, based on 10-frame hives, suggested for apiaries of different sizes producing extracted honey*

Equipment	Equipment suggested for apiaries of indicated sizes		
	65 colonies	250 colonies	850 colonies
	Number	*Number*	*Number*
Brood chambers	130	500	1,700
Supers	195	750	2,550
Bottoms	65	250	850
Inner covers	65	250	850
Outer covers, metal	65	250	850
Queen excluders	65	250	850
Bee escape boards, wood or wire, 2- or 4-way escapes	15	60	200
Drawn combs:			
Brood	1,300	5,000	17,000
Surplus	1,755	6,750	22,950
Honey extractors:			
2-frame hand reversible	1		
4-frame or larger		1	
45- or 50-frame		[1] 1	1
Honey pumps		[1] 1	[1] 1
Uncapping knives:			
Steam-hand	1	1	2
Power		[1] 1	[1] 1
Uncapping tanks	1	1	1
Storage tanks:			
50-gallon	3		
200-gallon		3	
500-gallon			3
Steam boilers:			
2-gallon	1		
Vertical, 2 to 6 horsepower		[1] 1	
Vertical, 6 horsepower			1
Honey heaters	1	1	1
Bottling tanks:			
10-gallon	1		
20-gallon		1	
40-gallon			1
Electric motors: [2]			
1 horsepower		1	1
½ horsepower		[1] 1	[1] 1
Scales, 1,000-pound platform	1	1	1
Motor trucks, 1½ tons		1	1

[1] Optional equipment.
[2] Where electricity is not available a 2-horsepower gasoline engine would provide the power for a 250- or an 850-colony apiary.

BROOD CHAMBERS AND SUPERS

As a matter of convenience the 10-frame Langstroth hive has been here chosen as a basis of comparison. It should be understood, however, that there are many other types and sizes of hives which, in the hands of capable beekeepers, can be used just as efficiently as the 10-frame Langstroth hive. Where a hive either larger or smaller than the 10-frame Langstroth is desired a proportionate reduction or increase in the number of hive bodies, frames, etc., will have to be figured. Provision is made for 2 brood chambers and 3 supers sufficient for the storage of approximately 135 pounds of honey per colony. Provision for 3 supers generally makes it possible to allow

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the honey to remain in the hives until it is thoroughly ripened. This results in a better quality of honey and may save some labor in that all the extracting can be done at one time. If chunk honey is produced it is preferable to use shallow supers. Five shallow supers are the equivalent of three full-depth supers.

FRAMES, BOTTOMS, INNER COVERS, OUTER COVERS, QUEEN EXCLUDERS, AND BEE-ESCAPE BOARDS

The equipment for the 10-frame Langstroth hive includes frames, bottoms, inner and outer covers, queen excluders, and bee-escape boards. Bee-escape boards are provided for approximately one-fourth of the colonies. This number depends on the quantity of honey that can be handled in a day and on whether the operator finds it desirable to have a bee-escape board for each colony or to use bee escapes on only a few colonies and some other means of removing the honey from the remainder of the colonies. Ten frames of drawn combs are provided for the brood chamber but in the supers for the storage of honey only nine frames are needed.

HONEY EXTRACTORS, HONEY PUMPS, AND UNCAPPING KNIVES

Extractors of the 2-frame, hand, reversible type are suggested for the smaller apiary, a 4-frame power or larger extractor for the 250-colony apiary, and the large radial extractor for the 850-colony apiary. The steam hand uncapping knife is provided for all groups, with the power uncapping knife optional. The use of gravity for filling the storage tanks is considered the best arrangement but when it is not possible to arrange equipment so that gravity can be utilized the honey pump will take its place. It is well recognized, however, that if the honey pump is not properly used it results in lowering the quality of the honey.

UNCAPPING TANKS

A small uncapping tank equipped with a strainer is suitable for the small operator. A larger uncapping tank is essential for the large commercial producer. The uncapping tank may be equipped with a strainer in which the cappings will drain, previous to being dried in the radial extractor, or the cappings may fall into wire baskets made to fit the radial extractor.

STORAGE TANKS

Storage tanks are based on a capacity of approximately one-fourth of an anticipated yield. Three 50-gallon tanks are suggested for the small apiary with storage facilities in proportion for the larger apiaries. The storage capacity should be sufficient to allow the honey to remain in the settling tanks at least 3 days before being drawn off into containers. From the standpoint of quality of product this is the minimum time that honey should be allowed to settle. Each storage tank should be equipped with a honey strainer. Inadequate straining and settling facilities account for much of the unsightly honey found on the markets.

STEAM BOILERS, HONEY HEATERS, AND BOTTLING TANKS

A small 2-gallon boiler is suitable for a hand steam uncapping knife and a vertical stationary steam boiler is recommended where the

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steam is used for a variety of purposes. It is necessary at times to heat honey to facilitate the removal of granulated honey from containers, to facilitate straining, to delay granulation, and to prevent fermentation. Owing to the lack of suitable honey-heating equipment on the market, most beekeepers have devised their own systems. It is only natural, therefore, to find that great quantities of honey are ruined through overheating. Ordinarily honey should not be heated over 160° F. and should then be cooled quickly after this temperature is attained. An agitator that does not incorporate air, in conjunction with the heating tank, enables the operator to heat honey uniformly and in the minimum length of time. For the small operation the most suitable heating system is to immerse cans of honey in hot water and allow them to remain until the proper temperature has been reached. If large quantities of honey are to be heated, correspondingly elaborate equipment must be installed. Bottling tanks are provided with the idea of preparing at least a portion of the production for disposal in pails or other small containers.

MOTORS AND ENGINES

If electricity is available an electric motor is to be preferred with a 1-horsepower motor for an apiary of either 250 or 850 colonies and a one-sixth horsepower motor if a power uncapping knife is used. If electricity is not available, a 2-horsepower gasoline engine is sufficient for either a 250- or an 850-colony apiary.

SCALES

Platform scales are included and, though not absolutely necessary, the best beekeepers usually maintain a colony on scales to observe the gain or loss in weight of colonies without examining the interior of the hive. The scales indicated in table 3 are mainly for use with scale colonies, but it would be possible for a beekeeper to use the platform scale in his bee yard until it is needed in the honey house.

MOTOR TRUCKS

A 1½-ton long-wheel-base truck equipped with an 8- by 12-foot rack is sufficient to handle all hauling for each of the two larger apiaries. This equipment is particularly necessary in the larger apiaries where there is much travel to and from outyards.

MISCELLANEOUS EQUIPMENT

A set of tools, bee brushes, smokers, and veils are essential in every apiary. In addition, a wiring board, frame-nailing device, wire embedder, workbench, and wheelbarrow are common to most apiaries. The investment in this equipment is small and to some extent a matter of personal convenience, and since the number of workers who use the articles are variable no attempt has been made to designate the number of specific articles of equipment for apiaries of different sizes. A wax press is needed if the beekeeper has a market for his beeswax in block form, but if the wax is exchanged for foundation or beekeeping equipment a wax press is not essential. Many operators of large apiaries are equipped to make most of their hives and other wood equipment, but no attempt has been made to list the

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amount of wood-working equipment necessary to do this, since it is purely a carpentry operation. Some extractors are equipped to dry cappings, but no special equipment is needed for melting them. If it is desirable to melt cappings, appropriate apparatus for doing so is on the market or one can usually devise suitable apparatus for this purpose.

BEEKEEPING IN CONJUNCTION WITH OTHER OCCUPATIONS

The relation of honey production to other productive enterprises has considerable influence on the size and organization of a particular apiary business. Often the time available for the care of bees limits the number of colonies handled. Again, where the bee yard is located near at hand so that the work may be done at odd times, the number may be limited by the accessibility of honey plants. Many of the beekeepers in the white clover region do not devote their entire time to beekeeping. The units in many instances are too small to utilize the full time of the owner or to provide an adequate income. Fifteen of the 40 beekeepers represented in this study in 1930, mainly those with small-to-medium size apiaries, had other business interests. The bee business of these 15 men was not operated as a hobby, but rather for profit, and the organization of their apiaries was comparable with those of other beekeepers with the same number of colonies.

Beekeeping was conducted as a part of a farm business by several cooperators. The number of colonies per beekeeper ranged from 54, cared for when the other farm work was not urgent, to 500 colonies, demanding so much of the time of the operator that supervision only was given to the other farm operations. One cooperator was engaged in school work which gave summer vacations free for his bees. Two ministers, a locomotive engineer, a bee inspector, a postal clerk, a janitor, and a part-time store employee also operated a limited number of colonies. As a general rule among the larger operators beekeeping is not conducted in connection with a farm business.

Beekeeping should not be combined with an occupation that does not permit the operator to give attention to the bees when most needed. Figure 2 shows the labor distribution, classified by operations, for a small, a medium-sized, and a large bee business, and is an illustration of the amount of time spent on bee work at different periods of the year. The smallest apiary required comparatively little time even during the producing season, whereas the largest required the time of one or more men during the greater part of the year. In general it may be said that a supplementary business which does not exact too much time of the worker and which requires a limited amount of attention during the 6 weeks or more of the busiest season of the bee year, is well adapted to combine with beekeeping. In addition, a certain fundamental knowledge of bee behavior and a genuine liking for bees are requirements considered essential to success.

MAN LABOR USED ON APIARIES OF DIFFERENT SIZES

The amount of man labor required in the care of bees and in the production of honey depends mainly on the size of the apiary and to a lesser extent on the quantity of honey produced, the number and distance between outyards, and the beekeeping methods employed.

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Table 4 gives the total man labor spent on apiaries of different sizes, divided among operator, family, and hired labor. For all size groups approximately 50 percent of the total time was represented by

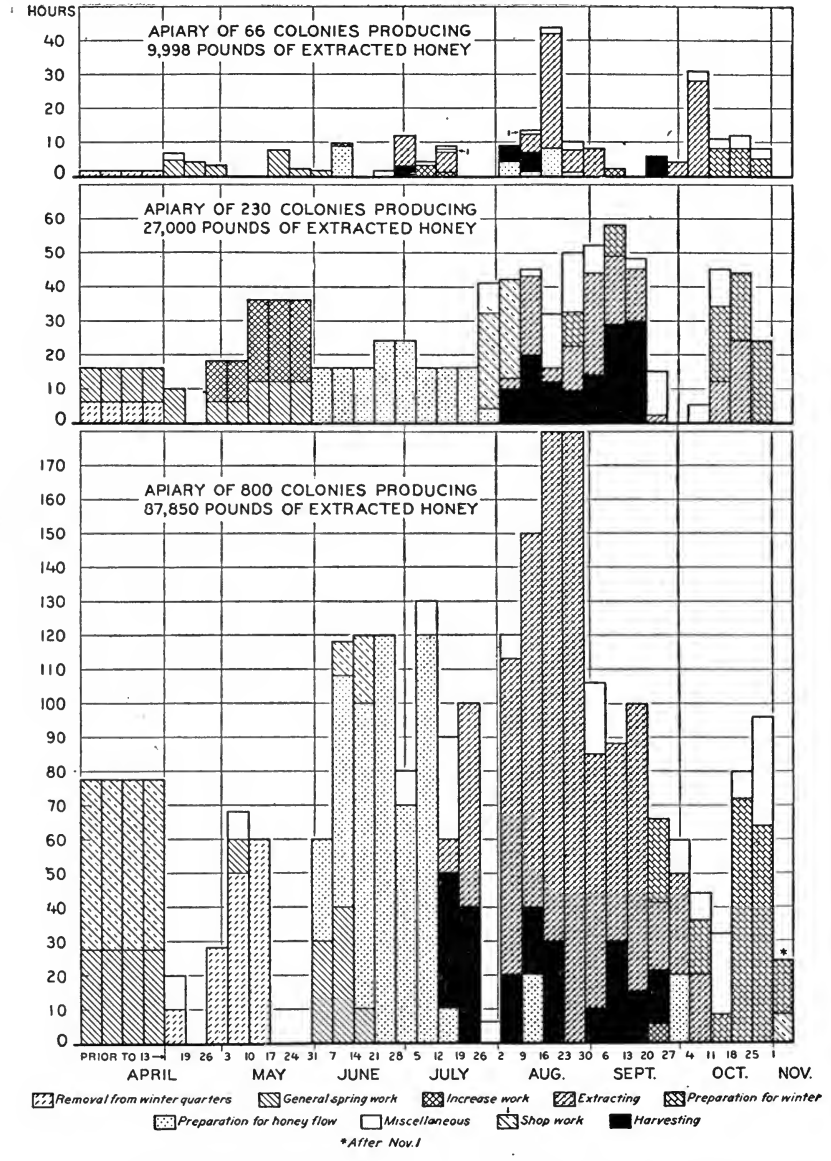

FIGURE 2.—SEASONAL DISTRIBUTION OF LABOR ON APIARIES OF DIFFERENT SIZES.

For each apiary the peak labor load usually occurs in August or September during the harvesting and extracting season.

operator's labor, 15 percent by family labor, and 35 percent by hired labor. For beekeepers with less than 100 colonies, hired labor was negligible. For the groups with over 300 colonies, hired labor amounted to from 33 to 64 percent of the total.

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TABLE 4.—*Operator, family, and hired labor on apiaries of different sizes, 1930–31* [1]

Size of apiary (colonies)	Average colonies per apiary		Man labor							
			Operator		Family		Hired		Total	
	1930	1931	1930	1931	1930	1931	1930	1931	1930	1931
	Number	*Number*	*Hours*	*Hours*	*Hours*	*Hours*	*Hours*	*Hours*	*Hours*	*Hours*
Less than 100	47	59	166.0	135.5	13.6	6.4	28.8	3.7	208.4	145.6
100 to 299	177	175	546.1	476.0	76.2	150.5	53.7	23.7	676.0	650.2
300 to 499	397	428	921.9	885.4	294.6	325.9	599.5	709.6	1,816.0	1,920.9
500 to 699	597	569	941.0	720.3	4.0	----	1,670.4	1,245.7	2,615.4	1,966.0
Over 700	757	805	1,446.4	835.7	909.6	815.8	1,006.5	2,119.1	3,362.5	3,770.6
Average	292	279	665.0	515.9	181.9	177.2	414.2	421.6	1,261.1	1,114.7

[1] All labor performed on the bee enterprise, including work on new equipment, is included in this table.

The division of labor as between work and travel shows that for apiaries of less than 100 colonies the travel hours were small, whereas for larger units they amounted to from 7 to 15 percent of the total (table 5). An automobile or truck is used largely to travel to and from outyards and the number of, and distance between, these have a direct bearing on the travel hours per apiary and per colony. In the group with less than 100 colonies, two beekeepers maintained outyards. The average travel hours in 1931 for this group were 0.2 hour per colony as against 0.6 hour per colony for the group with over 700 colonies. The number of outyards in the latter group varied from 8 to 15 per beekeeper. The most distant outyard was 25 miles from the home yard. The average hours spent on work of different kinds including the accompanying hours of travel are shown in table 6. Approximately 25 to 30 percent of the time is spent in harvesting and extracting and the remainder in other work with the bees.

TABLE 5.—*Work and travel hours on apiaries of different sizes, 1930–31* [1]

Size of apiary (colonies)	Average colonies per apiary		Labor per apiary						Labor per colony					
			Work		Travel		Total		Work		Travel		Total	
	1930	1931	1930	1931	1930	1931	1930	1931	1930	1931	1930	1931	1930	1931
	No.	*No.*	*Hrs.*	*Hrs.*	*Hrs.*	*Hrs.*	*Hrs.*	*Hrs.*	*Hrs.*	*Hrs.*	*Hr.*	*Hr.*	*Hrs.*	*Hrs.*
Less than 100	47	59	202.5	134.4	5.9	11.2	208.4	145.6	4.3	2.3	0.1	0.2	4.4	2.5
100 to 299	177	175	619.8	604.3	56.2	45.9	676.0	650.2	3.5	3.5	.3	.3	3.8	3.8
300 to 499	397	428	1,705.6	1,762.9	110.4	158.0	1,816.0	1,920.9	4.3	4.1	.3	.4	4.6	4.5
500 to 699	597	569	2,347.6	1,721.7	267.8	244.3	2,615.4	1,966.0	3.9	3.0	.5	.4	4.4	3.4
Over 700	757	805	3,039.0	3,248.4	323.5	522.2	3,362.5	3,770.6	4.0	4.0	.4	.6	4.4	4.6
Average	292	279	1,157.8	1,002.3	103.6	112.4	1,261.4	1,114.7	4.0	3.6	.4	.4	4.4	4.0

[1] All labor performed on the bee enterprise, including work on new equipment, is included in this table.

TABLE 6.—*Labor distribution by operations on apiaries of different sizes, 1930 and and 1931* [1]

Item	Labor on apiaries with—									
	Less than 100 colonies		100 to 299 colonies		300 to 499 colonies		500 to 699 colonies		700 colonies and over	
	1930	1931	1930	1931	1930	1931	1930	1931	1930	1931
	Number	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*
Apiaries	9	7	15	11	8	5	4	3	4	2
Average colonies per apiary	47	59	177	175	397	428	597	569	757	805
	Lb.	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*
Average yield of extracted honey per colony	109	15	67	88	66	99	142	49	73	57
	Man-hours	*Man-hours*	*Man-hours*	*Man-hours*	*Man-hours*	*Man-hours*	*Man-hours*	*Man-hours*	*Man-hours*	*Man-hours*
Remove from winter quarters	13.7	10.9	23.4	21.5	67.8	65.2	75.8	50.0	160.8	163.8
General spring work	25.9	14.4	71.5	94.3	224.3	194.4	210.8	150.8	293.4	622.6
Prepare for honey flow	21.4	19.4	112.9	78.6	225.9	317.4	404.1	336.4	510.6	796.1
Increase	7.0	2.5	26.4	31.1	37.2	107.4	134.2	66.5	128.0	332.4
Harvesting	24.3	6.9	78.9	73.3	121.6	158.6	222.4	173.6	249.7	473.5
Extracting	59.3	11.8	99.0	108.1	345.0	359.2	850.5	334.7	640.3	419.0
Disease control	7.6	8.8	21.4	16.0	52.5	53.8	13.1	25.8	40.2	139.7
Shop work, repairs	8.4	14.3	32.5	55.7	84.8	129.5	24.7	52.8	343.2	108.1
Prepare for winter	22.7	19.9	62.5	58.8	191.9	223.6	236.2	225.6	306.8	333.1
Miscellaneous	9.4	13.3	51.8	52.5	124.5	109.7	115.5	179.7	206.8	246.2
Total, per apiary	199.7	122.2	580.3	589.9	1,475.5	1,718.8	2,287.3	1,595.9	2,879.8	3,634.5
Total, per colony	4.25	2.07	3.28	3.37	3.72	4.01	3.83	2.80	3.80	4.51

[1] Labor not ordinarily required in the care of bees and in the production of honey, such as the making of new equipment, has been omitted from this table. For this reason the hours per apiary and per colony are somewhat less than those shown in tables 4 and 5.

The total time spent by individual beekeepers in 1930 ranged from 2 to 14.6 hours per colony. In 1931 the range was from 1.2 to 9.1 hours per colony. This wide range suggests that the methods followed by some beekeepers are more economical in the use of labor than those followed by others. In discussing the practices employed in the production of honey, some of these differences will be analyzed and some of the factors that illustrate economy and efficiency in the management of apiaries will be pointed out.

PRACTICES IN THE PRODUCTION OF HONEY

GENERAL SPRING WORK

Under "general spring work" are included all manipulations from the time of removal of the colonies from winter quarters to management for the honey flow, including early inspection for diseased and queenless colonies, uniting, feeding, evaluating and clipping of queens, removal of burr comb, cutting out queen cells, and the giving of room for brood rearing.

Twenty-nine of the 40 beekeepers clip the queens' wings either during an early spring inspection or at the time of supering. Seven beekeepers do not clip the queens' wings, and four plan to do so but because of the pressure of other work sometimes neglect to do it.

Those that "winter" in two brood chambers sometimes clear the top one of honey or reverse them. Feeding of sugar sirup or giving of full combs of honey saved from the previous season are the common

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methods of feeding when colonies are low in stores. Boiled amber honey was fed by three beekeepers.

Some of the cooperators who winter their bees in one brood chamber add a second one at the time of removal from winter quarters regardless of whether the bees are crowded. Some wait until the bees are actually crowded before a second brood chamber is added. Several provide about 15 pounds of honey in the second one when it is added.

The hours of man-labor for general spring work in 1930 ranged from 0.08 to 2.34 per colony, with an average of 0.44 hour per colony. In 1931 the range was from 0.06 to 1.8 hours per colony, with an average of 0.49 hour per colony.

This variation in labor is caused by a number of factors but much of the excessive time is due to the fact that (1) the beekeeper was the operator of a comparatively small number of colonies, had no other work to occupy his time, and for that reason spent more time with his bees than would otherwise be the case; and (2) the bees were not provided with adequate stores in the fall, so they came through the winter in poor condition, making it necessary to feed sugar sirup and otherwise nurse the colonies along in an effort to build them up to proper strength for the honey flow.

The average hours of general spring work for the group having less than 100 colonies in 1930 was 25.9 hours, or 0.55 hour per colony (table 6). The range was from 0.13 hour per colony for a beekeeper with 46 colonies to 2.34 hours per colony for a beekeeper with 58 colonies. The beekeeper who had the minimum of spring work had strong overwintered colonies that required no spring feeding, early spring inspection being the only labor. The beekeeper having the maximum of labor fed a considerable quantity of sugar sirup, had no other work to occupy his time, and gave much more labor to his bees than appeared necessary.

In the group with 100 to 299 colonies the average amount of general spring work in 1930 was 71.5 hours, or 0.4 hour per colony. The beekeeper with the maximum of man labor spent 2.8 hours per colony in 1930 and 1.8 hours per colony in 1931. This beekeeper had no other business interests and so spent nearly every favorable day in inspecting his bees. A total of 0.38 hour per colony was spent in feeding sugar sirup. The beekeeper with the minimum of labor in 1930 spent 0.08 hour per colony. His bees were wintered outdoors in quadruple cases and in the fall each colony was provided with at least six full frames of honey. Early spring inspection, with the adding of a brood chamber, was the only labor performed on the bees until the preparation for the honey flow. The beekeeper having the minimum of labor in 1931 spent 0.2 hour per colony. This beekeeper cellar-winters in single brood chambers. In the fall, if the bees do not weigh up to 70 pounds, full combs of honey are provided. About May 1, when the brood chamber is crowded, a second one containing some stores is added.

An examination of the range in labor among beekeepers with sufficient colonies to occupy their full time shows a variation in time requirements but not so marked as in the groups with a small number of colonies. In the group of over 700 colonies in 1930 the average amount of general spring work was 293.4 hours per apiary, or 0.39 hour per colony (table 6). The range was from 0.23 to 0.66 hour per

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colony. The beekeeper having the minimum of labor winters his bees in single full-depth brood chambers in quadruple cases. In the fall each colony is given 6 or 7 frames of honey. The colonies are unpacked about April 1 and are given another brood chamber containing 15 pounds of honey. The beekeeper having the maximum hours of labor winters his bees in two shallow brood chambers in the cellar. In the spring a third shallow is added. The use of this type of equipment where individual frames are examined entails a considerably longer time for spring inspection in comparison with the time required when standard full-depth brood chambers are used.

From an analysis of the labor and other items of feeding costs, it would seem to be good economy to save full combs of honey for winter and early spring stores rather than to feed sugar. A record was not kept of the quantity of honey consumed, but assuming that the leaving of full combs of honey valued at 3 cents per pound[1] was at the same rate as that of sugar, etc. (12 pounds per colony in 1930, and 9 pounds in 1931), the cost of the former method is much less than that of the latter. In 1930, 16 beekeepers having 5,886 colonies of bees fed a total of 70,895 pounds of sugar valued at $3,598.96. This feeding operation required 1,452 hours of man-labor and 3,032 miles of travel at an estimated cost of $910.16, making a total cost of $4,509.12, or $0.77 per colony. On the other hand, the 14 beekeepers having 4,083 colonies of bees who provided full combs of honey had a cost for honey of $1,469.88. Three hundred sixty-nine hours of man-labor and 357 miles of travel represent an additional charge of $206.32, making a total of $1,676.20, or $0.41 per colony. The cost per colony of feeding sugar was 36 cents more in 1930 than that of providing full combs of honey.

A similar comparison for 1931 showed that the cost of feeding sugar was 26 cents per colony greater than that of providing full combs of honey. On a colony basis the value alone of the sugar fed was approximately two-thirds greater than that of honey in the comb. In addition, the labor and power cost of providing full combs of honey was materially less than that of feeding sugar.

Among most beekeepers it is the practice to leave sufficient stores to carry the bees through the winter and start brood rearing in the spring, but when the type of honey is not suitable, or when there is not enough honey for wintering it is necessary to augment stores by the feeding of sugar sirup at the close of brood rearing, even though this practice is considered an expensive operation.

SWARM CONTROL AND PREPARATION FOR HONEY FLOW

In addition to swarm-control measures, the handling of queens, the supering, and the use of queen excluders are included here. Increasing the number of colonies and the control of disease, operations performed during this period, are discussed under separate headings.

Most of the beekeepers represented in this study used a modification of the well-known Demaree system of swarm control and supering while a few allowed the queen free range. By the former system of swarm control and supering the queen is separated from part of the brood.

[1] This value is based on honey in the comb, before extracting and placing in containers.

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The methods of swarm control and preparations for the honey flow as practiced by the cooperators are as follows:

(1) Twenty beekeepers allow their colonies to build up in two brood chambers. At the beginning of the honey flow the queen is put in the lower chamber either with the hatching brood or on empty combs. A queen excluder is put on, supers are put above in which frames of brood have been placed, and the chamber with the rest of the brood is put on top.

(2) Four cooperators put on supers whenever the colony appears crowded. These beekeepers do not use queen excluders.

(3) Two cooperators equalize their colonies during the spring building-up period. Five frames of brood and about 10 pounds of honey are provided in each 8-frame hive, and 6 frames of brood and the same amount of honey in each 10-frame hive. Colonies with less than the prescribed quantity of honey are supplied from those having a surplus. At the beginning of the honey flow the queen is confined on the emerging brood in the lower chamber by an excluder and supers are added, with the hive body containing the unsealed brood placed on top.

(4) The colony is allowed to build up in two brood chambers. The queen is placed in the lower brood chamber with 3 or 4 empty combs when the honey flow begins. The rest of the brood is put above the excluder with plenty of supers on top. Whenever the brood chamber is filled 3 or 4 of the combs are removed and put in the super directly above the excluder. Empty combs are put in the place of those removed. Among some cooperators who use the large hive, combs of honey on either side are removed and the same number of empty drawn combs are put in the center. The full frames are either set aside for fall feeding or given to other colonies.

(5) One cooperator used two brood chambers all the year. Sometimes the upper brood chamber is cleared of honey, or it may be reversed if the bees begin to rear brood in the lower one. If much honey is above, it is put below and precautions are taken to have the top chamber full of brood when supers are given. The cooperator who followed this method had much pollen in the combs and excessive swarming during certain seasons.

(6) When all the colonies are removed from the quadruple cases an extra chamber containing some honey is given to each. At the beginning of the fruit and dandelion bloom an excluder is put on the second chamber and a super is added. At the beginning of the main flow the queen is found and the frame she is on, with eight empty drawn combs, is put in a chamber on the bottom board. An excluder is put on, followed by supers, with the brood on top. Queen cells are removed from the brood put above. One cooperator practiced this method of swarm control.

(7) One cooperator who does not use queen excluders during the early period of the honey flow puts on supers as the colony becomes crowded. About 25 days before the honey is removed the colonies are examined and the queen is confined by an excluder to the lower chamber.

(8) One cooperator winters his bees in two shallow brood chambers. In the spring a third "shallow" is put on and, as a rule, at the beginning of the honey flow, the queen occupies the two top ones. The top brood nest, which is filled with brood, is raised by placing supers in

between. As the brood emerges the top body becomes filled with honey to be used as stores in the fall. In the fall the lower chamber is removed and the colony is wintered in the top and second chamber.

(9) After the bees are out of winter quarters and have had a flight, one cooperator inspects from the bottom by lifting up the brood chamber from the bottom board. If anything seems to be abnormal an inspection is made from the top. During this examination the colony is given a clean bottom board and a shallow food chamber is placed underneath the brood chamber. Later a second full-depth brood chamber is placed between the two chambers. At the beginning of the honey flow, the colony is handled as follows: The original brood chamber is put on the bottom board, then a super containing empty combs, the excluder, the shallow food chamber, and finally the brood which was in the second brood chamber are placed.

(10) The colony is wintered in a single large brood chamber containing 11 frames. A hive body is added soon after unpacking and the queen is kept below with an excluder. Two weeks before the beginning of the honey flow the excluder is removed to allow the queen to go above. When the queen becomes well established in the second hive body, she is put below the excluder in the original brood chamber with supers in between, and the rest of the brood is placed on top. The cooperator who uses this system has observed that the brood chamber is used more fully for brood and the surplus honey is carried above; thus the queen is not crowded by the storage of honey in the brood chamber.

(11) One cooperator winters the bees in 1-story, or 1½-story hives. A brood chamber, either full depth or shallow, is added at the time of unpacking. The colony builds up in the 2 full-depth brood chambers or in the full-depth and 2 half-depth brood chambers. Later the queen is confined by an excluder to the lower full-depth brood chamber, and at the beginning of the honey flow this brood chamber is put above the supers after the queen is taken out and again put below the excluder in a hive body of selected empty combs.

(12) The colony is allowed to build up in two brood chambers. At the beginning of the honey flow the queen is put in the lower one with the sealed brood. An excluder is put on, two supers are added, and on top of these supers another excluder is placed. Then the brood chamber containing the unsealed brood is put on the top. An auger hole in this chamber allows the young queen, which is raised there, to go out and mate. In this way additional young queens are raised. This method of swarm control was practiced by one cooperator.

The yield of honey and character of the honey flow have a decided influence on the labor required during the period of preparation of bees for the honey flow. The manipulations during this period are principally associated with swarm-control measures which involve the addition of supers not only to give room to the bees but also to provide space for the storage of honey. Where the honey flow is intense it is more difficult to control swarming and more labor is required than in cases where the honey flow is slower and more uniform. Again, in seasons of a large honey flow more supers must be added, which in turn entails additional labor.

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The hours of man-labor spent in preparing colonies for the honey flow in 1930 ranged from 0.11 to 2.35 per colony with an average of 0.64 hour per colony. In 1931 the range was from 0.08 to 1.5, with an average of 0.67 hour per colony.

The beekeepers with the minimum hours of labor in 1930 and 1931 wintered their colonies in two standard brood chambers in which the bees build up during the spring period. At the beginning of the honey-flow the previously clipped queens were confined by excluders to the lower brood chambers with the emerging brood. Either 1 or 2 supers were put on above the excluders, depending on the strength of the colony, and the rest of the brood was put at the top. Queen cells built from brood placed above the excluder were not removed. The beekeeper with 0.11 hour of work per colony had a yield of 87 pounds per colony, whereas the one with 0.08 hour per colony had a near failure.

The beekeeper with the maximum hours of work per colony in 1930 wintered his bees in the cellar in one brood chamber. In the spring the colonies were equalized in number of frames of brood and stores, and as soon as this brood chamber was fairly well filled another brood chamber was added. When the queen was laying well in this second brood chamber, a bottom board was placed under it. A board extending from the ground at an angle to the entrance of the second brood chamber causes the young bees in the lower brood nest to go into the second one. A queen excluder was put above the second chamber and additional supers were added as needed. After 3 weeks the brood chambers were reversed and the extra bottom board was removed. During the period of preparation for the honey-flow a total of 2.35 hours of work was spent per colony, of which 1.9 hours represented swarm-control measures and 0.46 hour was used in moving bees. The yield was 88 pounds per colony and much swarming was reported. This is a complicated and not very effective method of swarm control and involves much more work than should be required during this period.

The beekeeper with the maximum number of hours per colony, in preparation for the honey-flow in 1931, wintered the colonies in the cellar in a full-depth brood chamber and a shallow food chamber. At the first spring examination the chambers were reversed. The colony built up in this way until the first super was added by lifting up the full-depth brood chamber and placing the super between the shallow and the brood chamber. Later the brood chamber was put on the bottom board, then an empty super on which the excluder was placed, then the shallow food chamber, and the brood which was in the second brood chamber below. Empty supers were always put under the excluder until partly filled and later put above the excluder when the next super was added.

This method of swarm control seems to work well in the case of this beekeeper, although it is rather complicated. The total time in preparation for the honey-flow was 1.5 hours per colony, of which 0.7 hour was in swarm control and 0.8 hour in moving bees to distant bee pasturage when it was apparent that the honey-flow in the immediate neighborhood would be practically a failure. As a result of moving the colonies to favorable pasturage, a yield of 121 pounds per colony was obtained, which more than justified the extra time spent in moving.

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INCREASE IN COLONIES

Comparatively few of the cooperators were attempting to increase materially the numbers of their colonies; the majority were striving only to maintain a fixed number. Where winter and spring losses were heavy as well as losses from foulbrood, as was the case with many beekeepers, several new colonies were needed to make up for these losses.

The several ways of making increase were:

(1) Through natural swarming.

(2) Through the purchase of package bees with queens. As a rule 3-pound packages are used where white clover is the principal nectar-producing plant, while in sections where sweetclover is common and the colonies have a longer period in which to build up to full strength, particularly in Minnesota, 2-pound packages are commonly used.

(3) Through the dividing of the brood and supplying the queenless part with purchased or home-reared queens.

(4) Through the rearing of queens from brood placed in a hive body above a screen or excluder and containing an auger hole from which the queens can fly out to mate. After these queens are laying this brood chamber is set off on its own bottom board.

(5) Through division of strong colonies. Several beekeepers, in sections where sweetclover is the principal honey plant, divide their strong colonies early in the season. Such divided colonies usually build up during the dandelion and early white clover flow to colonies of full size by July 15, and during favorable seasons both divisions usually store a good crop of honey.

(6) Through the purchase of full colonies of bees.

(7) Through other means. One cooperator who does not use bee escapes in removing the honey makes increase in the following manner: As many bees as possible are smoked down from the filled supers. The supers with some adhering bees are then taken to the honey house and left uncovered. The bees fly to the window where they collect in a hive which contains brood and a queen. In this way an increase of around 20 colonies is made each year.

The inventory at the beginning of 1930 showed a total of 12,098 colonies of bees for 40 cooperators. At the beginning of the honey-flow a total of 11,662 colonies was reported or a net loss of 436 colonies. Eleven reported an increase, 24 a decrease, and 5 had the same number as at the beginning of the season. The number of colonies reported at the end of the year was 12,246 or a net increase of 1.2 percent for the year. Twenty-three reported a gain, 15 a decrease, and 2 had the same number as at the beginning of the year. The hours of labor in making increase amounted to 779½ or 1.37 hours per colony for the 23 beekeepers who reported an increase of 569 colonies.

The total increase in numbers of colonies in 1931 was 182 or a percentage increase of 2.3. Of the 28 cooperators represented in that year, 12 reported a total increase of 452 colonies, 14 reported a total decrease of 270 colonies, while 2 had the same number of colonies at the end as at the beginning of the year. The labor used by 12 beekeepers, who reported an increase of 452 colonies, amounted to 693 hours or 1.53 hours per colony.

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CONTROL MEASURES FOR AMERICAN FOULBROOD

American foulbrood is widespread in sections of the white-clover region in which this study was made but, because the statistics are inadequate, it is impossible to estimate accurately the damage done. Foulbrood not only takes a serious toll in the destruction of colonies but distracts the beekeeper's attention from work having directly to do with honey production. The disease attacks all races of bees, and strong colonies are as susceptible as weak ones. It is impossible to manipulate or manage colonies so that they will not contract this disease, although precautions may be taken to prevent its spread in an apiary. Much worry and financial loss may be avoided by dealing promptly and effectively with the disease upon its appearance.

Of the 28 beekeepers represented in 1931, 18 operators, or 64 percent, reported American foulbrood. Two hundred and eleven, or 2.7 percent of the total colonies represented, were infected. Of the 18 reporting foulbrood, 5 destroyed the bees and combs; 5 saved the bees and destroyed the combs; 4 saved the bees and treated the combs, and 4 destroyed the bees and treated the combs. A majority of those who saved their bees shook them on to new foundation. A variety of methods were employed in treating combs, from soaking them in alcohol-formalin solution to treatment with water-formalin.

Although a decidedly greater immediate loss is incurred when the bees and infected brood combs are burned, this method has been adopted in a majority of the States. By following this practice the danger of infecting healthy colonies is materially lessened. No specific method of management absolutely prevents the introduction of American foulbrood, although there are precautions that every beekeeper should observe, such as not buying bees or old equipment unless they are known to be free of disease, not locating an outyard where foulbrood is prevalent, and in preventing robbing insofar as is possible.

The data gathered are not detailed enough to show the costs of the different methods employed, but it is certain that American foulbrood in an apiary, irrespective of how it is handled, is expensive. Of 18 apiaries representing 211 affected colonies, 74 colonies valued at $296 and 2,910 combs valued at $291 were destroyed. Fifty-six gallons of alcohol-formalin solution valued at $84 was used in treating 2,820 combs. Seven hundred fifty-one hours of man-labor and 73 miles of travel involved an additional cost of $304.81. The total cost amounted to $975.81, or $54.21 per apiary and $4.62 per colony.

HARVESTING

Harvesting includes the operations involved in the putting on of bee escapes, the brushing of bees from the combs, and the removal of supers of honey from the bee yard to the honey house. Of 40 beekeepers in 1930, 30 used bee escapes and 10 brushed and smoked the bees out of the supers.

The labor requirements for a group of beekeepers who use bee escapes, show some saving in man-labor through the use of the escape. The users of escapes, represented by 8,205 colonies producing 674,229 pounds of honey, harvested 270 pounds of honey per hour of labor compared with 194 pounds of honey per hour of labor for

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a group of beekeepers operating 2,919 colonies and producing 237,461 pounds of honey who did not use bee escapes.

In addition to some saving in labor through the use of bee escapes an additional advantage is claimed in that the bees are gentler and that there is less robbing during seasons of a light honey crop.

EXTRACTING

The labor required to uncap and extract honey depends on several factors such as the type of uncapping knife, the type and size of extractor, and the manner in which the honey is conveyed from the extractor to the storage tank. The plain uncapping knife, the steam-heated hand knife and the steam-heated power knife are all in general use. The extractors in use varied from the 2-frame hand to the 45-frame radial power extractor.

The quantity of honey extracted per hour of man-labor varied from an average of 76 pounds with a 2-frame hand extractor and a plain hand knife to 133 pounds with a 45-frame power extractor and a power knife (table 7). Seventeen of the twenty-eight apiaries represented, averaging 523 colonies each, were equipped with 45-frame radial extractors and either steam hand or power knives. The smaller apiaries used extractors which varied in size from the 2-frame hand to the 4-frame power, with a cold hand or steam hand knife. The steam hand knife was the one most generally used among small as well as large operators. If a beekeeper has a business of sufficient size, or if he has only a few colonies and contemplates fairly rapid expansion, he will usually find it advantageous to install the larger radial extractor.

TABLE 7.—*Quantity of honey extracted per hour of man-labor with specified equipment, 1930* [1]

Type and size of extractor	Type of uncapping knife	Apiaries	Colonies per apiary	Honey extracted per hour of labor
		Number	*Number*	*Pounds*
2-frame hand	Plain, hand	3	65	76
Do	Steam, hand	5	60	85
4-frame power	do	3	115	99
45-frame power	do	4	371	114
Do	do	[2] 7	684	127
Do	Power	[2] 6	437	133

[1] Certain apiaries are omitted from this table because, for a given unit, the size and type of equipment was not the same.

[2] Honey pumps were in use in these groups of apiaries.

Where the extracting plant is not so arranged that the honey flows from the extractor to storage tanks by gravity, it appears that some saving in man-labor can be made through the use of a honey pump. Seven beekeepers, operating 45-frame extractors with honey-pump attachments, and using steam hand uncapping knives, extracted an average of 127 pounds of honey per hour of labor as against an average run of 114 pounds per hour for extractors of the same size but where the honey pump was not used. Beekeepers represented in the latter group lifted the honey to the storage tanks by hand. Where honey is pumped to storage tanks it is preferable to allow it to run first from the extractor to a small tank or sump to which the honey pump is

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attached. With this arrangement there is less danger of air bubbles forming in the honey, since the fall of the honey level in the sump may be more readily seen and the pump stopped before air is pumped into the honey.

Comparatively little difference in output of honey per hour of man-labor was found as between the use of the power uncapping knife and the steam hand knife. As shown in table 7, the honey extracted per hour of labor with a 45-frame extractor and power knife was 6 pounds more than with a 45-frame extractor and a steam hand knife.

Cappings were (1) dried in a radial extractor, the dried cappings being melted up at the convenience of the beekeeper, and (2) dried in a simple draining box or tank into which the cappings fall as they come from the uncapper; and were melted up after they had been drained as free as practicable of honey.

Where the cappings are dried in a radial extractor, an uncapping box, tub, or can serves as a receptacle for the cappings. Where the power uncapper is used, a tub is placed on a platform similar to those used under supers but larger and is usually handled with a truck lift. Where a 5-gallon can is used to catch the cappings a hopper is arranged to direct the falling cappings into the can. Two men usually lift the tub and dump the honey and cappings into the radial extractor, while 1 man performs this operation when a 5-gallon can is used. With a steam hand knife it is customary to allow all cappings to drain in an uncapping tank before they are dried in the radial extractor.

When cappings are dried in a draining box they should be left in the box for several days. For fairly large operations, when cappings are dried in a radial extractor the capping tank should be of sufficient size to hold the cappings from a day's run, as it is convenient to handle cappings at the close of each day or at the beginning of the following day.

The honey that remains after the cappings are melted is sold for baking or manufacturing purposes, as it is usually spoiled for table use.

The following is a description of the interior arrangement of the honey house and the extracting methods of an extensive operator. The house is 60 by 30 feet, 2 stories in height, and has a basement which serves as a storage room for supers. The first-floor arrangement is such that a truck can be driven into one end of the building opposite an unloading platform which is adjacent to the extracting room. The unloading platform and floor of the extracting room are slightly lower than the level of the floor of the truck, which makes it possible to load and unload with the minimum of labor (fig. 3). The tank room and storage room occupy the remainder of the first-floor space to the rear of the extracting room. The cellar has a summer temperature of approximately 60° F., which serves to keep moth injury at a minimum. Supers are stored in the basement until cold weather, when they are moved to the top floor, where they are cleaned, sorted, and stored for the winter.

A 45-frame radial extractor, a revolving comb rack, a steam hand knife, and a plain draining box are in use (fig. 4). The uncapping box is of galvanized iron 2 feet wide by 2 feet deep and 3 feet long with a bar across the middle, thus making it possible to suspend a few combs in the box. The box rests on a frame made of 1-inch angle iron. At the side of the uncapping box there is a device to catch the drip from the knives. Two drain pipes from the knives empty into this device.

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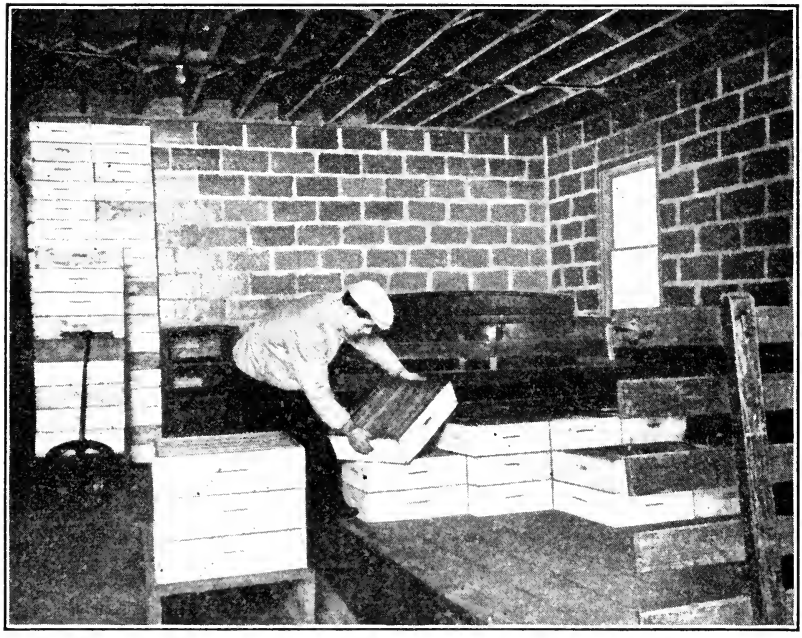

FIGURE 3.—Unloading filled supers of honey from the truck to truck racks. To the left is shown a loaded lift truck which is used to move the filled supers to the extracting room.

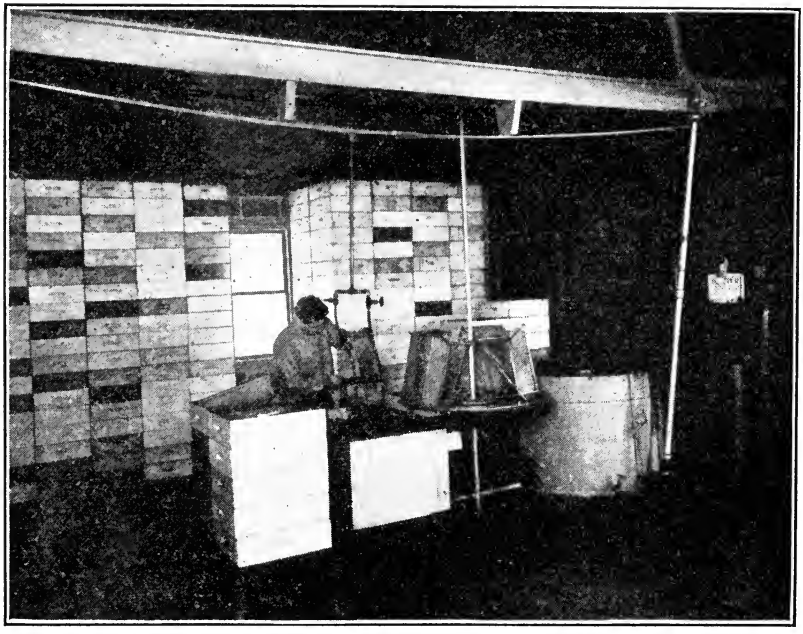

FIGURE 4.—Interior of the extracting room showing the arrangement of the extractor, revolving comb rack and uncapping tank. It requires about 2½ minutes for 2 men to empty and refill the extractor.

The inlets from the steam pipes to the knives are directly over the uncapping box so that the rubber hose from the knives hangs vertically in the box to catch the drip. The steam outlet is 2 feet 6 inches above the box and there are 2 valves to regulate the steam supply to the 2 knives. The edge of the revolving comb rack extends over the uncapping box 3 inches, which serves to prevent the drip of honey to the floor. The steam pipe to which the knives are attached and all cross bars on the uncapping box swing out of the way to facilitate transfer of the cappings to the extractor.

The pump is equipped with an 8-inch pulley and a 1½-inch pipe for the vertical rise and a 3-inch galvanized pipe for the horizontal run. A piece of rubber hose 6 or 8 inches long connects the pump and the riser. This piece of rubber hose pulsates with each turn of the pump and evens the flow of honey in the pipe. The pipe from the pump

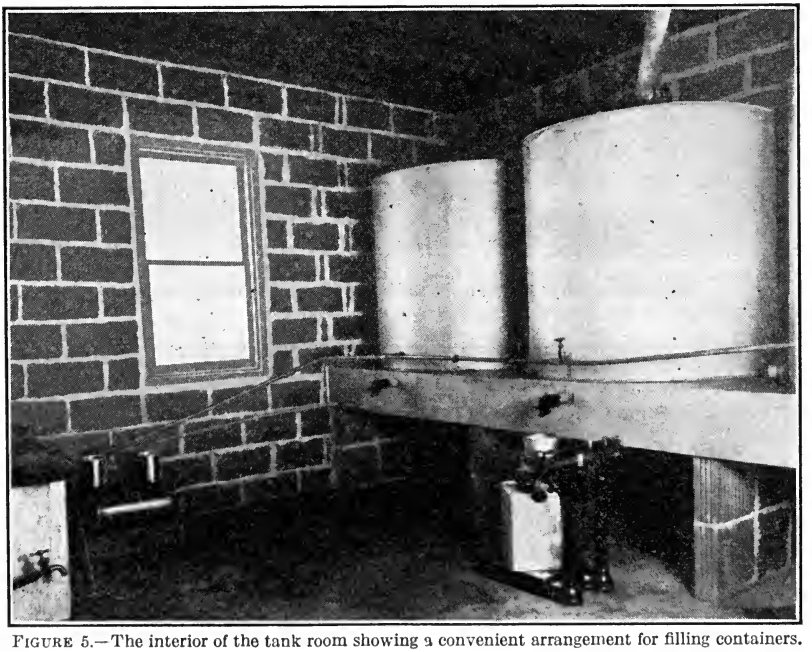

FIGURE 5.—The interior of the tank room showing a convenient arrangement for filling containers.

empties into a strainer box which is held on the bottom of the storage tank by a prop to the ceiling. The strainer box has ⅞-inch vertical strips at the four corners and is bound half way up by screen wire cloth placed at the outside of the corner strips. A cheesecloth bag suspended inside of the strainer box is held in place by a ⅞-inch square frame attached to the top of the box. Before honey is drawn off the tank any foreign matter in the bag is removed, permitting the strainer to be used several times without washing.

There is a honey outlet from the uncapping box into the extractor through a pipe and short hose connection. From the extractor to the pump and from the pump to the pipe line there are similar connections. The extractor is equipped with a steam coil in the bottom which can be used to melt any honey that might granulate.

The storage tanks, which are in a separate room, are placed about 35 inches above the floor level (fig. 5).

The supers, 10 to a load, 2 long and 5 high, are brought in from the unloading platform on a light lift truck. Two men, one at each end of the uncapping tank, uncap on a frame rest and place the combs in the revolving comb rack until a sufficient number are ready. The extractor is filled by placing the combs one at a time. The combs are taken from the extractor 4 or 8 at a time, being first pushed slightly forward to free them from the periphery of the extractor, thus giving room to grasp them. Using 8 combs in a super, 8 in each section of the revolving comb rack, and 8 in each of the 5 sections of the extractor, makes it easy to keep each set of combs separate, as a division is always evident between the lots. The combs from the extractor are placed in supers on a truck rack, 20 empty supers constituting a load.

The cappings are shoveled out of the draining box into galvanized-iron bushel baskets and are dumped into the extractor for drying. The dried cappings are transferred through a chute to the basement, where they are allowed to remain until a convenient time for melting.

WINTERING

That winter losses may be held at a minimum, every effort should be made to prepare the colonies properly for the winter. The prime requisites are strong colonies of young bees, young vigorous queens, and sufficient stores of good quality to carry the colonies through the winter and well into the spring, together with adequate protection against the cold.

Three general types of wintering are practiced in the white-clover region—wintering in bee cellars, wrapping in tar paper, and wintering in packing cases.

CELLAR WINTERING

Until comparatively recent times cellar wintering, particularly in the northern border of the white clover region, was largely practiced. Although this method is still common it is being displaced by other methods. The reported winter loss for 1930 was 7.2 percent for the cellar method of wintering. This relatively high winter loss was attributed largely to poor ventilation, which in turn resulted in a lack of uniformity in temperature and in an excessive amount of moisture.

Of the 40 beekeepers reporting in 1930, 10 wintered all and 6 wintered a portion of their bees in cellars and wrapped the remainder in tar paper. Of the 10 beekeepers who wintered all their bees in cellars, 7 used the 1-story hive; 1 used a 1½-story, and 2 used a 2-story hive.

Two of the cooperators wintered their bees in a cellar 60 by 20 by 10 feet, which has a concrete floor and side walls, a shingled roof, and 1 foot of flax straw under the ceiling. Another beekeeper has a 16 by 16 foot cellar under the barn.

Four have cellars of the type illustrated in figure 6. The sides are built of logs which are extended across the top to form a ceiling over which straw and dirt serve as insulation. Most of these cellars are provided with ventilating shafts. In a cellar of this type, but which lacked ventilating facilities, 150 colonies of bees were placed in the fall of 1930 with a loss of 56 colonies during the winter. On examination in the spring of 1931 it was found that moisture had collected in

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the hives and most of the combs were moldy. This perhaps is an extreme case, but is illustrative of what may take place in greater or less degree in poorly constructed and operated bee cellars. Bee cellars of the type shown in figure 6, in which the ceiling is lined with straw and ventilating shafts are installed, give a fair degree of success.

The following is a description of a cooperator's modern bee cellar in which winter loss of bees has been small. It is about 7 feet 6 inches in depth and the top of the wall is at the ground level. The construction is of hollow tile with a concrete floor. The roof of the building, of galvanized iron, is gabled and supported by iron posts. The ceiling is lined with a 2-foot layer of clover chaff held in place by heavy woven wire. The entrance is at one end. An air shaft extends up through the ceiling and at its lower end has a blanket cover that can be unfolded to control ventilation. An electric fan used to draw out the stale air is housed in a separate building and is connected with a 16-inch galvanized-iron pipe which extends into the bee cellar.

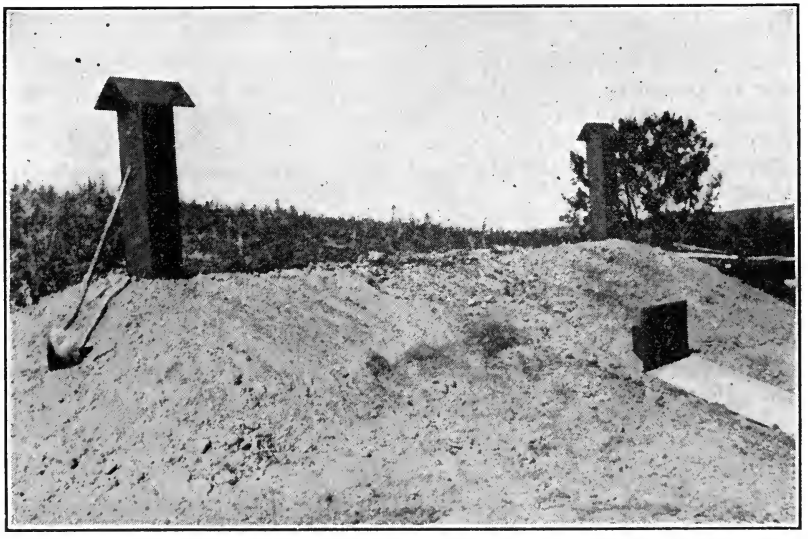

FIGURE 6.—Bee cellar of the dug-out type. This cellar has a dirt floor and plank ventilating shafts. The side walls and top are constructed of logs. More permanent cellars of this type have concrete floors and side walls.

This iron pipe is separated at two places and reconnected with tape, to lessen vibration. The noise of the motor that operates the fan does not disturb the bees. A long underground air-intake pipe of 22-inch tile branches into two 16-inch pipes inside the cellar and extends to each end. Both outlets of the pipe in the cellar may be closed by shutters that operate through the ceiling. A thermometer which can be drawn up through the ceiling is used to note the temperature without entering the cellar. An electric fan with thermostat automatically controls the temperature within a variation of a few degrees.

WINTERING IN TAR-PAPER CASES

The tar-paper case is becoming increasingly popular for wintering bees. The winter loss for this method of wintering was 3.5 percent. Of the 40 cooperators, 8 used tar paper exclusively and 6 wrapped a

portion of the colonies in tar paper and wintered the remainder in cellars. Six of those who wintered in tar paper exclusively used 2-story and 2 used 1½-story hives.

Three cooperators pack their bees for winter with slater's felt and chaff packing; one uses a shallow packing tray under two colonies and the other two winter on summer stands in one and one-half story hives with no packing below. Another cooperator uses 2 layers of corrugated paper around the sides of the hive and 1 layer of waterproof paper which extends 1 foot above the top. This paper is tacked and cleated around the bottom. About 6 inches of shavings are placed on top of the hive. The paper is folded in and the top is put on and tied down with cord. Waterproof paper is used on the outside at the rate of 1 roll for 20 colonies. No bottom packing is used. Another cooperator uses a mixture of clover-chaff, shavings, and cut straw and 4 inches of bottom packing. Telescope outer covers and inner covers are used. When the packing is removed in the spring it is sorted, placed in piles, and covered with tar paper.

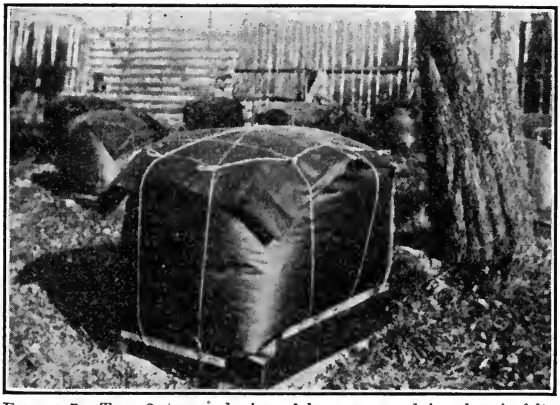

FIGURE 7.—Two 2-story colonies of bees wrapped in slater's felt. The hives are set in a packing tray and the insulating material is a mixture of planer shavings and sawdust. Note the windbreak in the rear. Where a natural windbreak is not available, it is desirable to provide a fence for wind protection, particularly on the north and west of the yard.

Two-story colonies of bees wrapped in slater's felt are shown in figure 7. The materials required for such a package are: (1) Regular entrance blocks to contract entrances down to about 3 by ⅜ inches; (2) two 32-inch laths and two 16-inch laths; (3) one tunnel strip, 2 by 32 inches; (4) twelve six-penny box nails; (5) about 40 feet of binder twine; (6) one sheet of slater's felt 11 feet 4 inches long for the packing case, one sheet 3½ feet long for cover and four six-penny box nails for pinning the case.

Packing trays are used under the hives. These trays are 2 feet 2½ inches wide, 3 feet 2½ inches long, and about 3¾ inches deep. The rim of the tray and the band to hold the rear end of the hives are 1- by 4-inch strips and are placed 4 inches from the outside of one of the long sides of the tray.

The procedure in packing is as follows: The hives are removed from the summer stands to make room for the bottom packing trays. Then the tray, filled with packing material, is placed on the stand. The hive is then placed on the tray and the tunnel strip is placed in position and secured by a nail through each end into the bottom board. The slater's felt in the form of a cylinder about 6 to 8 inches in diameter is unrolled around the tray and the ends are lapped a few inches and pinned with a nail. The lower edge of the felt is brought up against and even with the bottom of the tray and one of the 32-inch laths is placed against the tunnel strip so that its lower edge is even with the lower side of the tunnel strip. Then a 32-inch

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lath is placed in position at the rear and 16-inch laths are placed at either end. Three nails are used in each of the front and rear laths and 2 in each of the end laths. Now the ends of the felt are pinned with 2 or 3 additional nails. The nails used to fasten the strips are allowed to protrude about one-quarter of an inch, to facilitate ease of removal and so that twine can be fastened to them.

Planer shavings and sawdust are dumped in at each end of the case and packed down, especially at the corners, sufficiently to give shape to the case. Then more packing is added and the upper part of the felt is folded in so that the cover can be put in place and tied down. The twine is allowed to remain in a continuous length and the cover is tied down in the way shown in figure 7. After the case is packed and tied an opening about 2 inches by ⅜ inch is cut through the felt

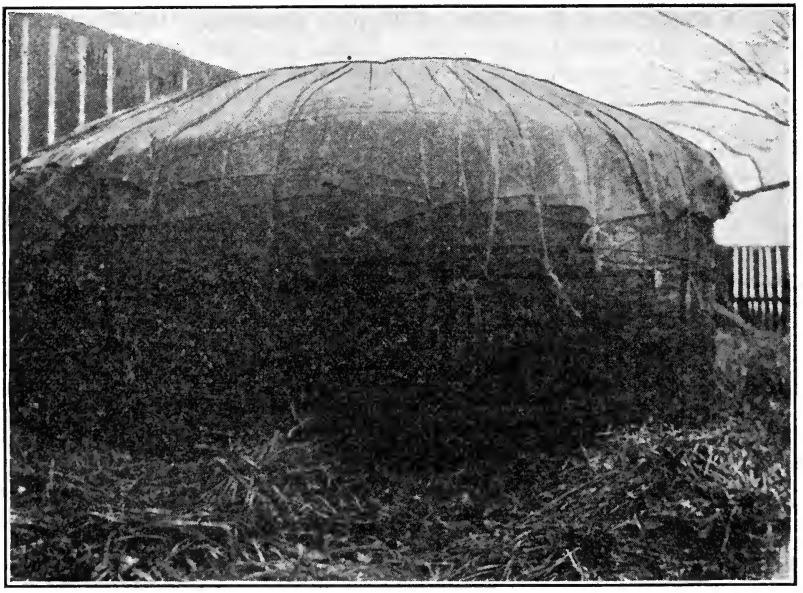

FIGURE 8.—Packing material sufficient for approximately 80 colonies of bees with a tar-paper covering and securely tied down with string. The material consists of planer shavings, sawdust, laths, tunnel strips, and tar paper. The material from each yard is packed in that yard where it is handy for the next season's use.

into the tunnel just under the front lath, directly in front of the inner entrance.

The packing material from the cases is stored in the way shown in figure 8. To hold this material together and keep it dry, a circular bin is formed from a piece of woven-wire fence about 32 feet long, the ends being lapped to form a bin the right size to hold the packing material to be accommodated. Three of the long pieces of slater's felt are used to line the inside of the wire bin, and additional paper is added as packing progresses. All laths and tunnel strips are placed on top, followed by all-paper covers and long sheets of packing-case paper, the top layer radiating from the center and so placed that it will shed water. A knot is tied in the middle of about 20 strings used to tie the cases, leaving each string about 20 feet from the knot to the end. This knot forms the hub, which is placed at the center of the top of the pile, and the string is made to radiate like the spokes

of a wheel and is tied down firmly to the wire. In this way the packing material is kept dry and at hand, where it is convenient for use the following fall.

WINTERING IN PACKING CASES

Seven beekeepers reported wintering all their colonies in packing cases with a winter loss of 4.5 percent. Of this number, 5 used a 1-story and 2 used a 2-story hive. Two wintered a portion of their colonies in packing cases and the remainder in double-walled hives.

The type of packing case showed considerable variation, but the quadruple case (fig. 9) is most generally used. Six cooperators used this type of case. One of them winters in a single brood chamber, using sawdust for packing material. In the spring at the time the bees are removed the packing material is stored in the cases for use

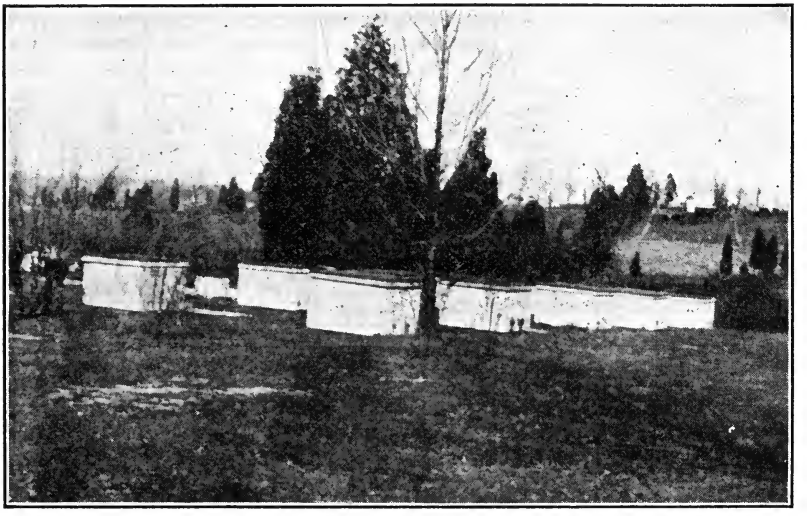

FIGURE 9.—Colonies of bees in two brood chambers packed in quadruple cases with sawdust as the insulating material.

the following year. Another uses a single brood chamber which is left permanently packed.

One beekeeper uses 2- to 4-colony wooden cases in which the bees are allowed to remain throughout the year. These cases have drop backs and lift tops and the brood chamber is left permanently packed.

Two beekeepers winter their bees in single cases. One uses wooden cases and 1-story hives. The other has cases of galvanized iron with an inner casing of cypress lath to hold the packing material of shavings, which are put in from the top. These cases fit down over a 2-story colony and are set on an extension of the bottom board. The top is covered with a tray held in place by rivets. The winter entrance is through a slot, cut in the iron, into a ⅞-inch portico and a ⅜-inch contracted inner entrance. The packing material is allowed to remain in the cases, which are stored at one end of the yard when not in use.

COMPARATIVE COST OF WINTERING BEES BY DIFFERENT METHODS

The cost of outdoor packing of colonies is somewhat greater than cellar wintering, but the tendency seems to be toward the former.

Of the two general methods employed in outdoor wintering the tar-paper package is the cheaper. In 1930 the comparative cost was 25 cents per colony for cellar wintering, 31 cents for tar paper, and 39 cents per colony for packing in permanent quadruple winter cases. Packing in tar-paper cases involves the largest amount of man-labor. Travel with automobile or truck was least where the cellar method of wintering was employed (table 8).

TABLE 8.—*Cost of wintering bees by different methods, white-clover region 1930*[1]

Item	Outdoor wintering				Cellar wintering (10 apiaries having 2,655 colonies)	
	Tar-paper cases (8 apiaries having 1,534 colonies)		Quadruple packing cases (7 apiaries having 2,967 colonies)			
	Quantity	Cost	Quantity	Cost	Quantity	Cost
		Dollars		*Dollars*		*Dollars*
Fall expense:						
Man-labor, hours	539¾	269.87	812½	406.25	431	215.50
Truck or automobile, miles	369	19.19	1,019	57.05	495	30.34
Tar paper, twine, etc., dollars		73.69				
Interest, depreciation, and repairs, dollars				425.45		228.90
Spring expense:						
Man-labor, hours	245	98.00	571½	228.60	409	163.60
Truck or automobile, miles	336	17.10	843½	45.64	528	31.54
Total cost, dollars		477.85		1,162.99		669.88
Cost per colony, do		.31		.39		.25
Man-labor per colony, minutes	31		28		19	
Truck or automobile travel per colony, miles	.46		.63		.39	

[1] Includes only those apiaries in which all the colonies were wintered in the same way.

CASH EXPENSES FOR APIARIES OF DIFFERENT SIZES

The cash outlay for apiaries of different sizes is shown in table 9. Of these items a large part of the use of automobile and truck is represented by travel to and from outyards, and the greater number of outyards and the consequent greater number of miles traveled largely account for the greater cost for use of automobile and truck with the larger apiaries. Beekeepers with less than 100 colonies, as a rule, conducted their business at the home bee yard, whereas those in the larger-size groups, in some instances, had a dozen or more outyards. In the group having less than 100 colonies, only 3 beekeepers used an automobile or truck in the conduct of their business, with the result that the average cash cost for use of automobile and truck was only $5.36 per apiary in 1930 and $13.05 in 1931. In the groups with 100 or more colonies the miles of travel ranged from slightly less than 100 to over 5,000 miles per apiary, with a corresponding cash cost for automobile and truck in the first instance of slightly more than $3 and in the latter case of nearly $500 per apiary. The latter case involved a beekeeper whose prospects for a honey crop were poor in his immediate neighborhood, so he hauled his bees to distant bee pasturage and obtained a fair crop of honey, whereas had his colonies remained at home his crop of honey would have been a near failure.

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TABLE 9.—*Cash expenses for apiaries of different sizes, 1930–31* [1]

Item	Less than 100 colonies		100 to 299 colonies		300 to 499 colonies	
	1930	1931	1930	1931	1930	1931
	Number	*Number*	*Number*	*Number*	*Number*	*Number*
Beekeepers	9	7	15	11	8	5
Average colonies	47	59	177	175	397	428
Cash outlay per apiary:	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*
Auto and truck	5.36	13.05	49.55	41.27	71.78	106.35
Hired labor	11.52	2.16	17.75	13.62	213.39	261.39
Supplies	24.76	15.95	50.11	36.63	89.96	160.73
Bees and queens	6.28	14.98	75.82	65.99	174.48	221.73
Permanent equipment and repairs	27.85	68.49	167.75	112.90	309.73	115.75
Apiary rental	3.62	2.43	17.75	18.11	36.25	24.66
Containers	34.25	6.69	89.61	100.11	190.82	257.23
Other items	3.24	2.72	23.49	14.26	61.80	42.70
Total per apiary	116.88	126.47	491.83	402.89	1,148.21	1,190.54
Total per colony	2.49	2.14	2.78	2.30	2.89	2.78

Item	500 to 699 colonies		700 colonies and over		All apiaries	
	1930	1931	1930	1931	1930	1931
	Number	*Number*	*Number*	*Number*	*Number*	*Number*
Beekeepers	4	3	4	1	40	27
Average colonies	597	569	757	776	292	258
Cash outlay per apiary:	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*
Auto and truck	160.79	255.77	193.86	143.30	69.61	73.62
Hired labor	656.90	392.57	367.74	300.00	154.39	109.25
Supplies	361.31	135.35	459.88	728.34	124.47	90.84
Bees and queens	126.59	147.00	59.38	24.00	83.34	89.05
Permanent equipment and repairs	280.38	319.10	369.86	88.00	196.14	123.91
Apiary rental	58.00	67.25	100.80	123.00	30.60	24.60
Containers	614.64	158.27	397.20	293.60	180.66	118.61
Other items	63.34	57.69	88.00	57.00	37.03	22.94
Total per apiary	2,321.95	1,533.00	2,036.72	1,757.24	876.24	652.82
Total per colony	3.89	2.69	2.69	2.26	3.00	2.53

[1] Based on extracted honey sold in cases of two 60-pound cans and in 165-pound kegs. Marketing charges are not included.

The expense for hired labor was small on apiaries of less than 300 colonies because most of the labor was performed by the owner and his family, whereas on the larger apiaries the charge for hired labor was one of the major items of cash expense. All beekeepers with 300 or more colonies hired some labor. The range in cost of hired labor for this group was from $5 for an operator with 355 colonies to $1,267 for an operator with 670 colonies. The former had an abundance of family labor and only a fair yield of honey, while the latter had no family labor and a very good yield.

The charge for supplies includes such items as sugar bought for feed and packing materials used in the winter packing of colonies. The cash expense to those beekeepers who buy sugar for feeding could be materially reduced by providing full combs of honey, rather than feeding sugar sirup. If sugar had not been fed the average cash costs would have been reduced by about 10 percent in both 1930 and 1931.

The purchase of bees and queens represents an appreciable cash outlay for some size groups. As a rule these purchases were to maintain the number of colonies in the apiary, but in some instances the

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expense was incurred to increase the number of colonies, and then the expense for this item was partially offset by the increase in inventory at the end of the year. The purchase of bees and queens was particularly heavy in 1931 in the group with 300 to 499 colonies, amounting to an average of approximately $222 per apiary mainly due to the purchase by 2 beekeepers of a large number of package bees and queens to replace winter and spring loss of colonies. Cash expenses to many beekeepers who wish to make increase could be reduced by the division of strong colonies early in the season and the introduction of home-produced queens rather than by the purchase of package bees. In 1930, 11 beekeepers bought a total of 558 packages of bees at a cost of $1,791, or $3.21 per package, while in 1931, 12 reported the purchase of a total of 626 packages at a cost of $1,947, or $3.11 per package. If increase had been made by division rather than by the purchase of package bees, the average cash costs would have been further reduced by about 5.5 percent in 1930 and by 12 percent in 1931.

The cash outlay for repairs and permanent equipment is a substantial item of expense for some size groups. In some instances the expense incurred for permanent equipment is partially offset by the increase in inventory at the end of the year. In addition, some immediate saving might be made by holding to the minimum the purchase of permanent equipment.

Apiary rental represents the amount paid in cash or in honey for the use of land occupied by bee yards. When honey was exchanged for the use of bee-yard site it was charged at the market price and the value was credited to honey sales. If the yard was located on land owned by the beekeeper no charge was made for use of land, since the area occupied by each yard is relatively small and is often waste land, along a fence row, or in an orchard. The charge for apiary rental was in proportion to the number of bee yards required and amounted to a substantial sum for the larger apiaries.

The cash outlay for containers is confined to the purchase of 60-pound cans and 165-pound kegs, and for a given size group this charge varies directly with the yield obtained. For instance, in the group of less than 100 colonies per apiary in 1930, with a yield of over 100 pounds per colony, the charge for containers amounted to 73 cents per colony, whereas in 1931, with a yield of approximately 15 pounds per colony, this charge was only 11 cents per colony.

RETURNS FOR APIARIES OF DIFFERENT SIZES

The receipts per apiary during 1930 and 1931 were from 36 to 256 percent greater than the cash outlay for all groups, except in 1931, for the group of less than 100 colonies, which averaged $50 less than the cash outlay mainly because of the low yield of 15 pounds of extracted honey per colony (table 10).

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TABLE 10.—*Returns for apiaries of different sizes, 1930 and 1931* [1]

Item	Beekeepers with—					
	Less than 100 colonies		100 to 299 colonies		300 to 499 colonies	
	1930	1931	1930	1931	1930	1931
Beekeepers—number	9	7	15	11	8	5
Average colonies—do	47	59	177	175	397	428
Yield of extracted honey—pounds	5,081	855	11,805	15,467	26,076	42,531
Yield of comb honey—sections	127		673	503	1,920	2,158
Yield of wax—pounds	89	12	170	224	426	535
Receipts per apiary:						
Extracted honey—dollars	332.15	59.87	762.31	931.64	1,668.52	2,518.86
Comb honey—do	17.78	11.97	86.70	114.76	275.14	257.90
Wax—do	24.12	2.40	50.56	43.29	113.46	97.70
Inventory net increase [2]—do	41.54		79.00	9.35	316.69	
Other—do	.31	2.77	15.53	18.73	4.13	
Total—do	415.90	77.01	994.10	1,117.77	2,377.94	2,874.46
Cash costs—do	116.88	126.47	491.83	402.89	1,148.21	1,190.54
Other costs:						
Unpaid family labor—do	5.46	1.91	30.46	45.14	117.85	97.77
Operator's labor—do	83.03	54.23	273.03	190.42	460.94	354.14
Inventory net decrease [2]—do		38.31				34.56
Total—do	88.49	94.45	303.49	235.56	578.79	486.47
Total cost exclusive of interest—do	205.37	220.92	795.32	638.45	1,727.00	1,677.01
Interest at 5 percent—do	59.54	55.13	171.37	163.65	378.55	361.27
Total cost per apiary—do	264.91	276.05	966.69	802.10	2,105.55	2,038.28
Total cost per colony—do	5.64	4.68	5.46	4.58	5.30	4.76
Receipts, less cash costs: [3]						
Per apiary—do	299.02	−49.46	502.27	714.88	1,229.73	1,683.92
Per colony—do	6.36	−.84	2.83	4.08	3.10	3.93
Receipts, less total costs: [3]						
Per apiary—do	150.99	−199.04	27.41	315.67	272.39	836.18
Per colony—do	3.21	−3.38	.15	1.80	.69	1.95
Quantity of extracted honey per colony required to pay costs [4]—pounds	87	78	84	76	82	79

Item	Beekeepers with—				All apiaries	
	500 to 699 colonies		700 colonies and over			
	1930	1931	1930	1931	1930	1931
Beekeepers—number	4	3	4	1	40	27
Average colonies—do	597	569	757	776	292	258
Yield of extracted honey—pounds	85,000	27,746	55,462	44,000	24,832	19,112
Yield of comb honey—sections		1,500	960		761	771
Yield of wax—pounds	1,346	383	935	650	397	260
Receipts per apiary:						
Extracted honey—dollars	5,420.00	1,587.71	3,698.62	2,640.00	1,606.16	1,135.73
Comb honey—do		319.73	213.75		112.92	133.14
Wax—do	403.88	74.67	270.50	130.00	114.52	49.46
Inventory net increase [2]—do		100.71	72.75		105.86	
Other—do			212.50		27.97	8.35
Total—do	5,823.88	2,082.82	4,468.12	2,770.00	1,967.43	1,326.68
Cash costs—do	2,321.95	1,533.00	2,036.72	1,757.24	876.24	652.82
Other costs:						
Unpaid family labor—do	1.60		363.85	75.00	72.76	39.76
Operator's labor—do	470.50	288.10	726.90	367.20	332.61	202.83
Inventory net decrease [2]—do	37.22			663.36		25.90
Total—do	509.32	288.10	1,090.75	1,105.56	405.37	268.49
Total cost exclusive of interest—do	2,831.27	1,821.10	3,127.47	2,862.80	1,281.61	921.31
Interest at 5 percent—do	554.34	459.92	738.65	826.47	282.67	229.58
Total cost per apiary—do	3,385.61	2,281.02	3,866.12	3,689.27	1,564.28	1,150.89
Total cost per colony—do	5.67	4.01	5.11	4.75	5.36	4.46
Receipts less cash costs: [3]						
Per apiary—do	3,501.93	549.82	2,431.40	1,012.76	1,091.19	673.86
Per colony—do	5.87	.97	3.21	1.31	3.73	2.61
Receipts less total costs: [3]						
Per apiary—do	2,438.27	−198.20	602.00	−919.27	403.15	175.79
Per colony—do	4.08	−.35	.80	−1.18	1.38	.68
Quantity of extracted honey per colony required to pay costs [4]—pounds	87	67	78	79	82	74

[1] Based on extracted honey sold in cases of two 60-pound cans, and in 165-pound kegs at wholesale prices. Wholesale prices were approximately 6½ cents per pound in 1930 and 6 cents per pound in 1931. Marketing charges are not included. In 1930, unpaid family labor was charged at 40 cents per hour and operator's labor at 50 cents per hour. In 1931, unpaid family labor was charged at 30 cents per hour and operator's labor at 40 cents.

[2] Difference in inventory values of bees, buildings, equipment, and supplies.

[3] Minus denotes loss.

[4] With honey selling at 6½ cents per pound in 1930 and at 6 cents per pound in 1931.

The receipts exceeded the cash outlay plus value of unpaid family and operator's labor and interest on the apiary capitalization at 5 percent for all 5 size groups in 1930 and for 2 in 1931. The difference between receipts and expenses including interest for all size groups averaged $1.38 per colony in 1930 and $0.68 per colony in 1931. One beekeeper, having 795 colonies and a yield of 111 pounds of extracted honey per colony, had a balance of $3,805 after paying all expenses, including interest. Another, with 425 colonies and a yield of 40 pounds per colony, had receipts that were insufficient by $1,089 to pay all charges, including interest. In 1930 there were 24 beekeepers whose receipts exceeded their expenses including interest as against 16 whose expenses were greater than their receipts. The average yield for the former group was 111 pounds of extracted honey per colony as against an average of 50 pounds for the latter group. A similar comparison for 1931 showed 13 beekeepers whose receipts exceeded their expenses, including interest, and 14 whose expenses were greater than their receipts. The average yield of extracted honey for the former was 97 pounds per colony as against 46 pounds for the latter.

The comparatively lower returns as between 1930 and 1931 for apiaries in the same size group are largely explained by the yields obtained. The yields required to pay costs, with extracted honey selling at the wholesale price of 6½ cents per pound in 1930 and at 6 cents per pound in 1931, are shown in table 10. The average yields of extracted honey obtained in 1930 and in 1931 (table 11) were insufficient to pay total costs in 3 of 5 size groups in both 1930 and 1931. Because of inventory net increase, however, and receipts from sales of wax, comb honey, and some miscellaneous items, all groups in 1930 and 2 of 5 size groups in 1931 had receipts which exceeded total expenses. To realize a substantial income, a beekeeper must operate on a relatively large scale and he must obtain good honey yields.

TABLE 11.—*Production of honey by apiaries of different sizes, 1930 and 1931*

Year and size of apiary (colonies)	Apiaries studied	Colonies per apiary				Average production per apiary			Average production per colony [1]	
		First inventory	Second inventory	Average	Honey flow	Comb honey	Extracted honey	Wax	Comb honey	Extracted honey
1930	*Number*	*Number*	*Number*	*Number*	*Number*	*Sections*	*Pounds*	*Pounds*	*Sections*	*Pounds*
Less than 100	9	49	54	51	47	127	5,081	89	3	108
100 to 299	15	178	184	181	177	673	11,805	170	4	67
300 to 499	8	396	414	405	397	1,920	26,076	426	5	66
500 to 699	4	595	605	600	597	-------	85,000	1,346	-------	142
Over 700	4	850	819	834	757	960	55,462	935	1	73
Average	-------	302	306	304	292	761	24,832	397	3	85
1931										
Less than 100	7	62	53	58	59	-------	855	12	-------	15
100 to 299	11	177	185	181	175	503	15,467	224	3	88
300 to 499	5	407	421	414	428	2,158	42,531	535	5	99
500 to 699	3	574	644	608	569	1,500	27,746	383	3	49
Over 700	1	795	766	780	776	-------	44,000	650	-------	57
Average	-------	257	267	262	258	771	19,112	260	3	74

[1] Based on number of colonies for the honey flow.

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EFFECT OF YIELD ON COST OF PRODUCING EXTRACTED HONEY

The yield of honey in a given region is influenced by a number of factors. The honey flow may be reduced by a scarcity of honey-producing plants or by unfavorable weather conditions. There is little the beekeeper can do to combat unfavorable natural conditions, although if bloom is scarce in one locality some advantage may be gained by moving the bees to better pasturage. Some advantage of expected natural conditions may be taken by bringing the colonies up to full strength at the time heavy bloom is expected. This timely development of the strength of the colonies explains in part the difference in yield obtained under similar conditions by different beekeepers.

The yield of honey obtained in 1930 and 1931 is shown in table 11. In 1930 the range in yield of extracted honey for individual beekeepers was from 8 to 190 pounds and the average yield was 85 pounds per colony. In 1931 four beekeepers did not harvest any honey; the remainder had yields of extracted honey ranging from 6 to 148 pounds per colony. The average yield was 74 pounds per colony. In addition a small quantity of comb honey was produced in both years. Yields in 1931 in some sections were much lower than usual because of the prolonged drought which destroyed much of the bloom.

Yield per colony is the factor exerting the greatest influence on the cost per pound of producing honey and is an important factor in determining the profits from honey production. The influence of yield on the cost per pound of producing extracted honey in 30 apiaries for 1930 is shown in the following tabulation. In general as the yield per colony increased the cost per pound decreased. The average cost per pound for 14 beekeepers producing less than 80 pounds of extracted honey per colony was nearly three times as high as the average cost per pound for 14 beekeepers producing 100 pounds or more per colony.

Average yield of colony (pounds):	*Cost per pound (cents)*
190	3. 1
183	2. 6
155	2. 6
151	1. 8
136	4. 9
134	4. 0
130	2. 5
120	3. 6
118	4. 2
111	2. 7
104	5. 6
102	4. 6
102	2. 6
100	4. 7
88	6. 4
87	5. 5

Average yield of colony (pounds)—Continued.	*Cost per pound (cents)*
76	6. 6
71	7. 2
70	4. 2
67	6. 8
66	8. 9
64	4. 8
61	6. 3
55	9. 0
50	8. 4
40	12. 6
36	12. 8
34	19. 0
30	14. 1
14	20. 8

THE INDIVIDUAL APIARY

In order that a particular beekeeper may compare his business with that of other successful beekeepers, four representative apiaries have been selected and their organization and management are here discussed in considerable detail. Such a comparison is likely to suggest ways in which the organization and management of any indi-

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vidual apiary can be improved. The selected apiaries are operated by men who have been keeping bees for a number of years, and although doubtless some details of their business could be improved, these men are recognized as successful beekeepers. Table 12 gives a summary of their business.

TABLE 12.—*Summary of apiary business of four typical beekeepers, 1930–31*

Item	No. 1		No. 2		No. 3		No. 4	
	1930	1931	1930	1931	1930	1931	1930	1931
Colonies of bees	*Number* 66	*Number* 65	*Number* 265	*Number* 252	*Number* 505	*Number* 560	*Number* 660	*Number* 776
Yield of extracted honey	*Pounds* 9,998	*Pounds* 0	*Pounds* 9,600	*Pounds* 37,200	*Pounds* 96,000	*Pounds* 75,000	*Pounds* 50,000	*Pounds* 44,000
Yield of wax	115	0	110	680	1,900	1,150	740	650
Apiary capital:	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*
Bees	462	439	2,086	1,904	4,545	3,960	6,910	7,950
Buildings	25	24	300	290	1,100	1,040	4,320	4,220
Permanent equipment	372	343	2,765	2,654	3,874	3,793	3,338	4,223
Supplies	20	23	11	42	15	----	400	136
Total	879	859	5,162	4,890	9,534	8,793	14,968	16,529
Receipts:								
Extracted honey	599.88	0	624.00	2,232.00	6,240.00	4,500.00	3,125.00	2,640.00
Wax	34.50	0	30.00	136.00	570.00	207.00	222.00	130.00
Inventory increase [1]	----	----	----	----	----	----	1,561.07	----
Total	634.38	0	654.00	2,368.00	6,810.00	4,707.00	4,908.07	2,770.00
Cash costs:								
Auto and truck	3.75	----	84.78	82.44	186.24	211.14	176.05	143.30
Hired labor	----	----	10.80	1.00	607.80	565.15	455.00	300.00
Supplies	4.29	3.25	35.00	19.80	306.20	292.75	1,077.00	728.34
Bees and queens	1.80	----	40.00	20.00	198.90	886.90	225.00	24.00
Permanent equipment and repairs	6.64	2.80	25.71	8.96	52.20	291.78	849.80	88.00
Apiary rental	----	----	41.00	41.00	28.00	27.60	116.20	123.00
Containers	30.50	----	79.50	241.80	720.00	500.00	325.26	293.60
Other items	----	----	33.50	39.03	31.00	51.75	57.00	57.00
Total	46.98	6.05	350.29	454.03	2,130.34	2,827.07	3,281.31	1,757.24
Other costs:								
Unpaid family labor	26.60	4.80	15.80	48.60	----	----	404.20	75.00
Operator's labor	74.62	24.60	303.00	237.20	721.25	474.70	665.00	367.20
Inventory decrease [1]	6.74	45.11	271.27	214.98	259.55	5.89	----	663.36
Total	107.96	74.51	590.07	500.78	980.80	480.59	1,069.20	1,105.56
Total cost exclusive of interest	154.94	80.56	940.36	954.81	3,111.14	3,307.66	4,350.51	2,862.80
Interest at 5 percent	43.95	42.95	258.10	244.50	476.70	439.65	748.40	826.45
Total cost:								
Per apiary	198.89	123.51	1,198.46	1,199.31	3,587.84	3,747.31	5,098.91	3,689.25
Per colony	3.01	1.90	4.52	4.76	7.10	6.69	7.72	4.75
Receipts less total costs: [2]								
Per apiary	435.49	−123.51	−544.46	1,168.69	3,222.16	959.69	−190.84	−919.25
Per colony	6.60	−1.90	−2.05	4.64	6.38	1.71	−.29	−1.18

[1] Difference in inventory values of bees, buildings, equipment, and supplies.
[2] Minus denotes loss.

Beekeeper no. 1 operates a 66-colony apiary in connection with a general farm in east-central Iowa. White clover, sweetclover, and basswood are the main honey plants. The colonies are located in the home yard in close proximity to the farm buildings.

The honey house is a small 1-story building. Honey and supplies are stored in other farm buildings. The total inventory values as of 1930, of buildings, bees, equipment, and supplies amounted to less than $900 or approximately $13.50 per colony, which was far

less than the average capital for other apiaries of a comparable size. About four shallow supers are provided for each colony. A 2-frame hand extractor, a steam uncapping knife, an uncapping tub, an 85-gallon storage tank, and six barrels comprise the bulk of the remainder of the equipment. This cooperator has only the minimum of equipment. Many of the hives have been in use for 30 years and are seldom painted. He buys nothing except what is essential and thereby keeps his inventory at the minimum.

About the middle of April the colonies are unpacked and if any are light in stores they are given full combs of honey saved from the previous season. During the spring period the bees build up in two brood chambers. They are inspected from time to time for disease, quantity of stores, and rate of building up. Queenless colonies are either given a frame of brood from another colony or united with a queenright one.

Clipping of the queen's wings is not practiced nor are queen excluders used. One super is added at a time. Bee-escape boards are used in removing the honey, the honey is extracted, and the supers are put back on the colony.

Extracting is with a two-frame hand machine. The cappings, removed with a steam-heated hand knife, fall into a draining tub. The honey from the extractor is drained into a pail and carried to an 85-gallon storage tank equipped with a strainer. Later it is drawn off into 50-gallon barrels and sold wholesale in this type of container.

The colonies are wintered in two brood chambers on their original hive stands. Approximately 60 to 70 pounds of stores are left in the hive, making the feeding of sugar sirup unnecessary. About six layers of newspaper are placed on the inner cover and the same quantity is wrapped around the hive and folded under the metal roof cover. Tar paper is then wrapped over the newspaper up to the metal cover and tied with twine. The operator says he has been particularly successful with this type of wintering.

This beekeeper realized a good return in 1930 but because of a crop failure there were no returns in 1931. The apiary was operated with approximately 3¼ hours of man labor per colony in 1930 and with slightly more than 1 hour per colony in 1931. In both years cash as well as other costs were at the minimum.

Beekeeper no. 2 is in western Ohio in a locality in which sweetclover is an important honey plant. Alsike and white clovers are also grown but honey from these plants is not abundant except in favorable years. This beekeeper gives his full time to beekeeping during the bee year and operates approximately 250 colonies located in 6 outyards. The honey house is a 1-story structure with an estimated value of $300. A storage house is rented at a cost of $15 per year. The inventory value of buildings, bees, equipment, and supplies amounted to approximately $5,000, or $20 per colony. Approximately four extra full-depth supers are provided for each colony. Quadruple winter cases are used for wintering, and queen excluders and bee escapes are ample for the number of bees. An 8-frame extractor is driven by a gas engine. Three storage tanks with a combined capacity of 2,700 pounds are provided. The outyards vary in distance from the home yard of from 3½ to 12 miles. The miles of travel per apiary amounted to 5.45. The number of colonies for the honey flow was 265 in 1930 and 252 in 1931. This apiary was operated with a

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total of 664 hours of man labor or 2.5 hours per colony in 1930, and in 1931 with 719 hours or 2.86 hours per colony. Much of the increased labor in 1931 was due to the additional time required to harvest and extract the larger yield of honey obtained in 1931.

The colonies wintered in quadruple cases are unpacked about April 1, provided the weather is favorable. Those that are light in stores are given full combs of honey saved from the previous year's crop. The feeding of sugar sirup has no place in the management. When all the colonies are unpacked a second full-depth hive body is added.

When fruit trees and dandelion come into bloom, an excluder is put on the second brood chamber and a super is added. It has been observed that the incoming honey is not stored in the brood chamber, which would congest it, but is carried above the excluder.

At the beginning of the honey flow (June 5 in 1931) the colonies are examined, the queen is found, and her wings are clipped. Every queen that is found to be already clipped is replaced at this time. The queen, with the frame she is on, is put in a hive body on the bottom board with 8 empty drawn combs. Only 9 combs are used in the brood chamber. Because of more clustering space thus provided, brood appears on the outside of the last frames. A queen excluder is put directly above the brood chamber, then empty supers containing 9 combs and finally the brood is placed at the top. The put-up brood is later examined for queen cells which are removed.

Increase is made at the time of supering for the honey flow. Four to five frames of brood with adhering bees are placed in a separate body with drawn combs and are given a laying queen.

Bee-escape boards are used in removing the honey. The combs are uncapped with a steam hand knife, the cappings falling into a draining box. After draining, a capping melter is used. The honey is pumped from the extractor into storage tanks. The honey is strained through a fine-mesh wire screen into a hoop of coarse wire which supports a cheesecloth strainer inside. The honey is allowed to settle 48 hours before it is drawn off into 60-pound cans.

On sorting the combs those containing much pollen are soaked in a tub of water to which yeast has been added. The yeast loosens the pollen in the cells, after which the combs are run in the extractor which removes most of the pollen. That remaining dries up and falls out or is removed by the bees.

The colony is wintered in a single brood chamber on nine combs in quadruple cases. Straw and leaves are used for packing material. In the fall, six frames of honey from the last super are put in the brood chamber.

The receipts were about $545 less than the total cost in 1930 mainly because of the very poor yield of 36 pounds per colony, while in 1931 with a yield of 148 pounds of honey per colony, the receipts were approximately $1,170 greater than the total costs. The apiary capital is about the same as the average of the other cooperators who handle approximately the same number of colonies. The hours of man labor per colony, 2.5 in 1930 and 2.86 in 1931, were considerably lower than the average.

Beekeeper no. 3 is located in west-central Minnesota where, in most years, sweetclover is an important source of nectar. The bees build up on the dandelion flow. In favorable years white clover is

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plentiful. During 1930 and 1931, however, little honey was secured from white clover and during the dandelion bloom conditions were not very favorable. This apiary is operated by two brothers who have been particularly successful beekeepers. Starting in 1919 with 14 colonies, the business has been increased to 505 colonies for the honey flow in 1930 and to 560 in 1931. During the period 1925 to 1931, inclusive, the yield ranged from 135 pounds to 270 pounds per colony and in 3 of the 7 years it exceeded 200 pounds per colony. This apiary is operated in connection with a dairy farm, but during the bee year the owners merely supervise the work of the dairy. The colonies are located in 7 outyards which vary, in distance from the home yard, from 5½ to 11 miles.

The honey house is a one-story building, valued at approximately $1,000, and is provided with an extracting room and storage room. A bee cellar valued at $100 has a dirt floor and concrete side walls with a roof of poles over which straw had been placed and banked over with dirt. Two 12-inch tile intake pipes and an 18-inch tile outlet comprise the ventilating system. The total investment in buildings, bees, and equipment amounts to approximately $9,500 or $19 per colony (table 12).

Approximately four extra full-depth supers are provided for each colony. Queen excluders and bee escapes are ample for the number of bees. A 45-frame radial extractor driven by electric power, an old-style slow-running pump, a steam boiler, a capping melter, a power uncapping knife, a storage tank of 5,000 pounds capacity and 2 of 1,500 pounds capacity each, comprise the bulk of the remaining equipment.

Between April 1 and 15 the colonies are removed from the cellar and taken to the outyards where the hives are arranged in groups of six. Bricks or pieces of timber are used for hive stands. Used corrugated paper is placed in front of the entrances to keep the grass down.

The first inspection is made soon after removal of bees from the cellar to see that the colony is queen-right and has sufficient stores. The bottom boards are stapled to the first hive body which makes it necessary to lift out frames instead of reversing whole bodies without paying any attention to the condition of the lower brood nest. The removal of combs makes it possible to determine the condition of the brood chamber and make it clear for a good queen. At the second inspection a second brood chamber is given, the queen's wing is clipped, and the colony is again inspected for disease. When opening hives the inner cover is removed and the bees are shaken onto the ground in front of the entrance. The hive body is set off behind the colony on an empty body carried along for that purpose. When the excluder is removed it is placed in front of the hive, upside down. In replacing hive bodies very few bees are crushed.

At the beginning of the honey flow the queen is confined by an excluder to the lower brood chamber which is arranged to have a frame of honey next to each outside wall, two frames of hatching brood in the center, and the dark empty combs for the remainder. If the 2 brood chambers are fairly full of brood, 2 supers are added, otherwise only 1. Nine combs are put in each super. Supers of foundation (nine frames to a body, carefully spaced) are put directly above the excluder. The rest of the brood is put above. As the flow from sweetclover extends over a comparatively long period, more brood

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has to be put above the excluder at a later time. No attempt is made to cut queen cells built from brood put above the queen excluder because it has been observed that these queens disappear without the colony swarming.

In harvesting honey, bee escapes are used. The attachments between the supers are broken by twisting each one aside slightly so that the bees will largely clean up broken burr combs between them. The burr comb is not removed but is left until uncapping time.

A power uncapping knife is used. The combs are uncapped into a draining box and the cappings are dried in the extractor and then put into boxes; when convenient they are melted in a capping melter.

Extracting is with a 45-frame radial extractor. The honey is pumped to a heater by means of an old-style slow-running pump, where it is warmed to 100° F. before being strained in a centrifugal strainer.

Formerly all colonies were wintered in the cellar in 1-story hives but recently a portion of them have been packed in tar-paper cases holding two bodies. In the fall considerable uniting of colonies takes place. Two to six frames of honey are taken out of the last super and put down into the brood chamber for winter feed.

This apiary was operated with a total of 5.82 hours of man-labor per colony in 1930 and with 4.64 hours in 1931. The miles of travel per colony were 4.66 in 1930 and 6.28 in 1931. Much of the larger number of hours and miles of travel in 1931 compared with 1930 was due to the longer time in preparing for the honey flow and in harvesting and extracting the larger yield in 1931.

Because of excellent yields this apiary showed a good return in both 1930 and 1931. The capital investment is moderate and there appears to be a good balance between the different items of the capital set-up. The outyards appear to be well arranged.

The hours of labor and miles of travel per colony are somewhat higher than with some other apiaries of a comparable size. One item that tends to increase these requirements is the time and travel used in packing bees in tar-paper cases. The man-labor for this operation amounted to 0.9 hour per colony as against an average of 0.5 hour per colony for all colonies packed in tar-paper cases. The miles of travel for this operation were 1.4 per colony as against an average of 0.46 mile for all colonies. The rather large amount of time and travel is perhaps due in part to the fact that until recently the colonies have not been packed in tar paper and the operators are not particularly expert in this method of preparing bees for winter.

In 1930 the expense for sugar for spring feeding was $279 and in 1931 it amounted to $248. This expense could have been reduced somewhat had full combs of honey been provided instead of feeding sugar sirup. Then in 1931 approximately $886 was spent for bees and queens. The cash expense for this item could have been materially reduced had increase been made by division of strong colonies.

Beekeeper no. 4 is located in central Michigan, in an area where white and alsike clovers formerly predominated but where sweetclover is becoming increasingly important. At times basswood adds to the surplus. In the fall the bees build up on buckwheat, goldenrod, and aster and in the spring on willow, fruit bloom, and dandelion. The full time of this beekeeper is given to beekeeping with the ex-

ception of a little time spent in insurance adjusting and some shop work for others.

The honey house is two stories in height and has a basement. A truck can be driven into one end of the building opposite an unloading platform. This platform is slightly lower than the level of the floor of the truck which makes it possible to load and unload with the minimum of labor. The tank room and storage room occupy the remainder of the first-floor space. The top floor is utilized for storage purposes. The total capitalization per colony, including bees, buildings, equipment, and supplies amounted to slightly more than $20. This beekeeper has approximately 750 colonies of bees. There are 11 outyards and the distance from the outyards to the home yard ranges from 3 to 13 miles. Approximately 2 extra full-depth and 2 shallow supers are provided for each colony. Queen excluders are provided for all colonies and bee escapes are used on a portion of the colonies. One 45-frame radial extractor, 2 steam hand uncapping knives, 1 honey pump, 1 comb rack, 3 storage tanks of a total capacity of 12,000 pounds, 1 steam boiler, and 2 electric motors comprise the bulk of the remaining equipment.

Early in April the first inspection of outyards is made. None of the packing cases are opened, the colonies being judged by outside appearance only. If weather conditions are favorable the packing is removed about May 15. The colonies are then inspected for queenlessness, disease, and quantity of stores. Queens' wings are sometimes clipped at this time. Shallow division board feeders are used on colonies that are light in stores.

Just prior to the honey flow all colonies are examined, and the queen is put into the full-depth brood chamber with a queen excluder below the shallow one. At the beginning of the honey flow the queen and bees are shaken onto empty combs below the excluder, supers are put on, and the brood is put above. Later the colonies are again examined and queen cells found on the put-up brood are removed.

In harvesting, bee escapes are used on a portion of the colonies; the remainder of the honey is removed by smoking the bees from the supers. The honey is hauled to the honey house. Any bees left in the supers fly to a nearby window where a nucleus is kept to collect them.

The honey is uncapped by means of steam uncapping knives and is extracted in a 45-frame radial extractor. There is a revolving comb rack between the uncapping box and the extractor. The cappings are dried in the extractor. An old-style pump elevates the honey to storage tanks (three with a total capacity of 12,000 pounds) where it is strained through a cheesecloth sack in a square wire box extending to the bottom of the tank. A boiler furnishes steam for various uses including heat for the radiators in the honey house in cold weather. Two electric motors furnish the power.

The majority of the colonies in one full-depth brood chamber and a shallow food chamber are wintered in tar-paper packing cases. Two colonies are placed together on a shallow packing tray. Slater's felt, shavings, laths, and twine are the packing materials. As a rule the food chamber is fairly well filled with honey and late in the fall the colonies are fed sugar sirup until they attain a weight of approximately 115 pounds for those in 1½-hive and 75 pounds for those in

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single-hive bodies. In 1930, 700 colonies were wintered in 1½-hive and 90 in single-hive bodies.

The expenses including interest exceeded the receipts in both 1930 and 1931. A comparatively low yield in 1931 materially reduced the receipts for that year. The capitalization is relatively high, particularly that represented by buildings which resulted in a rather high interest charge. In both 1930 and 1931 large quantities of sugar were fed. Much of this cash expense could have been reduced had full combs of honey been provided. In 1930 a rather large cash expense was incurred in the purchase of permanent equipment and in the increase in numbers of colonies. Some of this expense is reflected in the increase in inventory values at the end of the year.

SUMMARY

White clover is widely distributed throughout the United States except in the arid regions. In the area comprising the northeastern portion of the United States and extending westward to the Dakotas and south approximately to the Ohio River and the Mason and Dixon Line, white clover reaches its greatest importance as a nectar-producing plant. Alsike clover is also grown in the region and during recent years sweetclover has become an important nectar-producing plant in many parts of the white clover region.

There are many large apiaries in the white clover region, but those of small-to-medium size predominate. The relation of honey production to other productive enterprises has considerable influence on the size and organization of a particular apiary business. Fifteen of the 40 beekeepers represented in this study in 1930, mainly those with small-to-medium size apiaries, had other business interests. In general, it may be said that a supplementary business which is not too exacting in time and that requires limited attention during the 6 weeks or more of the busiest season of the bee year is well adapted to combine with beekeeping.

Man labor is one of the principal items of expense in the production of extracted honey. The time spent in 1930 ranged from 2 to 14.6 hours per colony. In 1931 the range was from 1.2 to 9.1 hours per colony. The average was 4.4 hours per colony in 1930 and 4 hours per colony in 1931. For beekeepers with less than 100 colonies, hired labor was negligible. For the groups with over 300 colonies hired labor amounted to from 38 to 64 percent of the total. Approximately 25 to 30 percent of the time is spent in harvesting and extracting and the remainder in other work with the bees. The quantity of honey extracted per hour of labor varied from an average of 76 pounds with a 2-frame hand extractor and a cold knife to 133 pounds with a 45-frame power extractor and a power knife.

The cost of out-door packing of colonies is somewhat greater than cellar wintering, but the tendency seems to be toward the former, and of the two general methods employed in out-door wintering—wrapping in tar paper and wintering in packing cases—the tar-paper package is the cheaper. In 1930 the winter loss for cellar wintering was 7.2 percent; for the tar-paper case, 3.5 percent; and for packing cases, 4.5 percent.

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The receipts per apiary were from 36 to 256 percent greater than the cash outlay for all groups except, in 1931, for those of less than 100 colonies. The receipts for this group in 1931 averaged $50 less than the cash outlay mainly because of the low yield of 15 pounds of extracted honey per colony. The receipts exceeded the total costs including interest on the apiary capitalization at 5 percent for all 5 size groups in 1930 and for 2 in 1931. The comparatively lower returns as between 1930 and 1931 for apiaries in the same size group is largely explained by the yields obtained. The average yield in 1930 was 85 pounds of extracted honey per colony as against 74 pounds per colony in 1931.

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TIMBER GROWING AND LOGGING PRACTICE IN THE SOUTHWEST AND IN THE BLACK HILLS REGION

By

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AND

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UNITED STATES DEPARTMENT OF AGRICULTURE, WASHINGTON, D. C.

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INTRODUCTION

Timber culture, like the growing of farm crops, is necessarily governed in any country by the soil and climate, by the requirements of native forest trees, and by local economic circumstances. Lessons may be drawn from the experience of other countries, as the United States has drawn upon the forestry of Europe; but profitable methods of growing timber, particularly under the wide range of forest types and economic conditions in the United States, can be worked out only from actual experience and investigation, region by region. Hence, to meet the need for information on practical ways and means of growing timber profitably in the various parts of the United States, it is important that the results of these experiences and investigations to date be brought together and set forth in the

[1] The Southwestern Forest and Range Experiment Station is maintained in cooperation with the University of Arizona.

[2] The authors wish to acknowledge the cooperation of various members of the Forest Service and of other bureaus in the Department of Agriculture in preparing this bulletin. Valuable assistance has been rendered particularly by Quincy Randles, M. W. Thompson, and C. B. Morse. These and other members of the Forest Service have read the manuscript and have offered constructive suggestions. The information on insects, wild animal life, and diseases has been obtained largely from the Division of Forest Insects of the Bureau of Entomology and Plant Quarantine, the Bureau of Biological Survey, and the Division of Forest Pathology of the Bureau of Plant Industry.

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clearest possible way. The value of timber, with other economic considerations, is causing landowners more and more widely to study the possibility of profitable reforestation. These developments have created a general demand for information on the timber-growing methods adapted to the various types of forest growth in the United States and what these methods will cost.

The Forest Service has attempted to meet this demand in a series of publications dealing with 12 of the principal forest regions of the United States, of which the first was issued in 1926. The information presented has been gathered from many different sources, including the experience of landowners who have engaged in reforestation. An effort has been made to bring together the gist of what has thus far been learned about the growing of timber in the United States; and the results have been verified as far as possible by consultation with the forest industries, State foresters, and forest schools. This bulletin thus undertakes to set forth what are believed to be the soundest methods of reforestation as yet developed in common experience and study in the Southwest and Black Hills regions.

Various factors enter into the forestry problem in the Southwest to make its solution distinct from that for any other region. For one thing, only a small percentage of the land area in the region covered by this bulletin—and that only in the rougher country and at the higher elevations—is timbered. Nevertheless, these timbered areas are of first importance to the whole region, since they are located at the headwaters of the principal streams, and these, in turn, supply water for irrigation without which farming in the lower valleys would be impossible. Therefore, the effect of forests on stream flow is in this region a consideration paramount to that of any other forest use. But, aside from their watershed value, these forests are of more than ordinary economic value to the region as a source of wood for local use. This timbered area is surrounded by very extensive areas of nontimbered land both in New Mexico and Arizona and in the Great Plains; these open grazing and farm lands constitute an excellent market for locally grown timber.

On the other hand, adverse climatic conditions in the region are reflected in light timber stands of relatively slow growth. While the practices recommended herein for the production of full timber crops give every promise of resulting in heavier yields than would be expected from estimates based on present stands, the indications are that timber growing as a private industry will not be financially profitable under average conditions. Fortunately, a relatively large percentage of the timbered land is already in the hands of public agencies, and on these lands the practice of intensive forestry methods may be expected to go substantially farther than at present toward supplying local needs for timber, at the same time that the greatest possible protection is given to water supplies. Meanwhile, private lands are being cut over, and the fact that the most intensive forestry may be impracticable under private ownership does not lessen the prime necessity for their protection from devastation. The requirements here outlined as "minimum measures to keep forest lands productive" represent the lowest standards of practice that will assure keeping privately owned lands in such condition that, under subsequent public management, they can yield satisfactory timber crops without the almost prohibitive expense of planting.

Much of the timberland in the region supports a forage crop in addition to the timber. The proper utilization of this forage crop will return a revenue and at the same time will not be detrimental to the timber crop. Improper utilization of the forage crop has been found to be destructive to both forage and timber. Protection, therefore, takes a somewhat broader meaning than in some other regions where forage utilization is not so large a factor.

THE REGION

GEOGRAPHY AND PHYSIOGRAPHY

The territory covered by this bulletin comprises all of the forest area of New Mexico and Arizona, a strip along the southern edge of Colorado and Utah, and the Black Hills of South Dakota and Wyoming.

The designation "Southwest" is applied to the forested lands of Arizona, New Mexico, southern Colorado, and Utah, which fall into three fairly well-defined subregions (fig. 1). In the northern part are the high southern Rockies, which include the extensive mountain forests of northern New Mexico and southern Colorado, as well as several smaller areas in southern Utah. Across central Arizona and New Mexico lies the extensive, timbered Colorado Plateau which, speaking geographically rather than geologically, extends from southern Utah southward across the Grand Canyon to the Mogollon Rim, and eastward in New Mexico, taking in the Cibola (formerly Manzano) and Gila National Forests. Farther south is what may be called the border—the desert dotted with isolated peaks and ranges, the highest of which are forest clad. Prominent among these are the Sacramentos, the Chiricahuas, the Santa Catalinas, and Mount Graham. Many relatively small forest areas are found on these numerous disconnected mountain masses.

Two great rivers—the Rio Grande and the Colorado—pass through and drain the greater part of the Southwest. These rise in the mountains farther north, but pick up many important tributaries which have their sources in the mountains to the south. Wide extremes of altitude are encountered with corresponding climatic variation ranging from a few feet above sea level at Yuma to the crest of the Rocky Mountains at nearly 14,000 feet. As it descends from the higher mountains and plateaus, the forest cover gives way to less luxuriant forms of vegetation. At the lower limits, as in the Salt River Valley and in the Colorado River Valley at Yuma, climate and soil are suitable for growing citrus and other subtropical crops on irrigated land.

The Black Hills of South Dakota and Wyoming form an isolated mountain region of a generally lower elevation than the forest areas of the Southwest. It is characterized by forest-covered slopes and numerous permanent streams whose narrow valleys are well adapted to farming. The Black Hills is the source of many of the tributaries of the Cheyenne, itself an important branch of the Missouri River.

FORESTS

The saw-timber forests divide themselves readily into three distinct types, or tree associations, named after the predominant species in each. These are the ponderosa pine (*Pinus ponderosa* Laws.) type,

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by far the most extensive and most important, the Douglas fir (*Pseudotsuga taxifolia* (LaM.) Britt.) type, and the Engelmann spruce (*Picea engelmannii* Engelm.) type. Tables 1 to 4 show the total estimated stand by area, volume, forest type, ownership, and subregion. The tables exclude areas on which the timber is too scattering or of too small size to warrant commercial logging operations under any reasonable market conditions. They also exclude areas

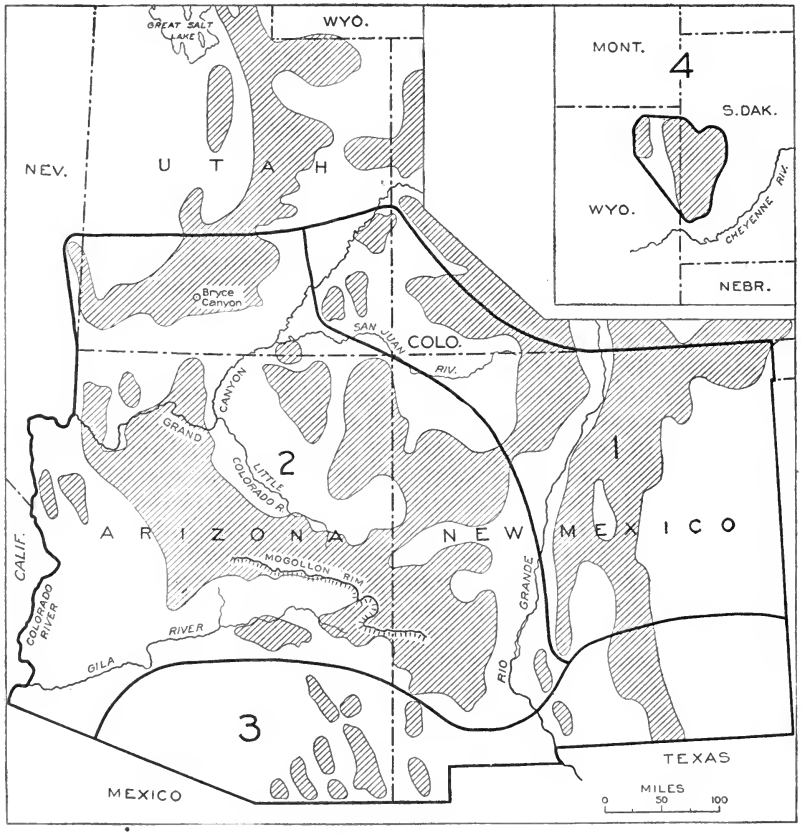

FIGURE 1.—Subregions comprising the southwestern and Black Hills forests.

regarded as inaccessible by present means of transportation, such as alpine stands and areas of very rough topography. According to these tables the total volume of commercial saw timber is nearly 42 billion board feet. The volume distribution by types is: Ponderosa pine, 84 percent; Douglas fir, 15 percent; Engelmann spruce, 1 percent. By class of ownership, the national forests contain 72 percent, Indian reservations and public domain 14 percent, States 2 percent, private 12 percent, or a total of 88 percent under public ownership. About 63 percent of the total volume is on the Colorado Plateau.

TABLE 1.—*Area and volume of saw timber in the Southwest by class of ownership and forest type*

AREA IN ACRES

Forest type and condition	National forests	Indian reservations	Other Federal	State	Private	Total
Ponderosa pine:						
Virgin	4,214,626	1,362,000	65,000	115,135	619,181	6,375,942
Cut-over	1,114,753	142,000	55,900	39,294	487,269	1,839,216
Total	5,329,379	1,504,000	120,900	154,429	1,106,450	8,215,158
Fir-spruce:						
Virgin	983,437	32,000		23,982	222,039	1,261,458
Cut-over	123,140	5,000			67,125	195,265
Total	1,106,577	37,000		23,982	289,164	1,456,723
All types:						
Virgin	5,198,063	1,394,000	65,000	139,117	841,220	7,637,400
Cut-over	1,237,893	147,000	55,900	39,294	554,394	2,034,481
Total	6,435,956	1,541,000	120,900	178,411	1,395,614	9,671,881

VOLUME IN MILLION FEET BOARD MEASURE

Ponderosa pine	25,577	5,562	12	537	3,357	35,045
Fir-spruce	4,427	379		159	1,568	6,533
Total	30,004	5,941	12	696	4,925	41,578

TABLE 2.—*Area and volume of saw timber by subregion and forest type*

AREA IN ACRES

Forest type and condition	Colorado Plateau	Border	Southern Rockies	Black Hills	Total
Ponderosa pine:					
Virgin	3,971,196	663,000	1,169,972	571,774	6,375,942
Cut-over	795,779	67,000	494,214	482,223	1,839,216
Total	4,766,975	730,000	1,664,186	1,053,997	8,215,158
Fir-spruce:					
Virgin	506,212	110,000	645,246		1,261,458
Cut-over	52,141	28,000	115,124		195,265
Total	558,353	138,000	760,370		1,456,723
All types:					
Virgin	4,477,408	773,000	1,815,218	571,774	7,637,400
Cut-over	847,920	95,000	609,338	482,223	2,034,481
Total	5,325,328	868,000	2,424,556	1,053,997	9,671,881

VOLUME IN MILLION FEET BOARD MEASURE[1]

Ponderosa pine	22,769	1,510	8,341	2,424	35,044
Fir-spruce	3,307	550	2,677		6,534
Total	26,076	2,060	11,018	2,424	41,578

[1] Commercial saw timber on areas exclusive of those cut over.

TIMBER CUTTING

Six more or less distinct lumbering centers are recognized. These are northern Arizona, northern New Mexico, southern Colorado, the Zuni Mountains, the Sacramento Mountains, and the Black Hills.

Cutting commenced in northern Arizona, northern New Mexico, southern Colorado, and the Zuni Mountains about 1880; in the Sacramento Mountains about 1905; and in the Black Hills about 1875.

Reference to tables 1 and 2 shows that out of more than 9,500,000 acres of timberland, only 21 percent has been cut over. By classes of ownership, 40 percent of the private and only 19 percent of the national-forest land has been logged. In considering the apparently huge percentage yet available, it must be remembered that considerable areas are so located that the timber cannot be marketed until there is a substantial rise in stumpage prices. Although there are many local variations in conditions, the present management problem is largely one of handling virgin stands.

DEVASTATED AREAS

Forest devastation as here understood implies the removal of forest trees in such degree that natural restocking in the near future is virtually precluded. Areas denuded of commercial timber but bearing appreciable seedling growth or scattering young trees approaching seed-bearing age are not regarded as devastated. Cutting alone rarely results in devastation in this region because even the most extreme type of clear cutting nearly always leaves a few trees capable of bearing seed. It is only when cutting is followed by fire that conditions approaching devastation are created. Theoretically, any denuded forest land under protection should eventually restock to trees, because seeds carried long distances by wind, birds, and rodents will give rise to occasional seedlings which in the course of time will become seed trees. Whether or not such areas should be classed as devastated depends, from a practical viewpoint, upon the time required for restocking. In order to establish a uniform concept, the term "forest devastation" has been applied in this bulletin to areas on which natural reproduction sufficient to form a commercial stand of timber is not expected to take place within 100 years.

An estimate of the acreage classed as devastated in this region is given in table 3. Although a considerable portion of this acreage occurs in national forests, the devastation in nearly all instances took place before the national forests were created. Large areas which actually have been devastated will probably always be inaccessible for logging, and for this reason are not technically classed as devastated. Such areas, made up largely of spruce burns in the high mountains, have been excluded from table 3.

TABLE 3.—*Area of devastated land in acres by forest type and ownership*

Ownership	Ponderosa pine type	Fir-spruce type	All types
Federal:			
National forests [1]	77,845	14,000	91,845
Indian reservations	4,500		4,500
State	2,200	1,000	3,200
Private	89,200	32,000	121,200
Total	173,745	47,000	220,745

[1] Devastated almost uniformly before inclusion in national forests.

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CONDITIONS AFFECTING THE PRACTICE OF FORESTRY

The primary basis for the formulation of measures necessary for effective forest production must be sound information regarding habits and requirements of different species of trees. A very important secondary consideration, however, is the degree of influence exerted by economic conditions and public sentiment, since these largely determine the extent to which the application of any proposed measure is practical. It is the purpose here to present a birdseye view of these factors as well as a discussion of silvical facts.

ECONOMIC CONSIDERATIONS

FOREST VALUES

The total annual consumption of forest products in Arizona and New Mexico prior to 1930 is estimated at 350,000,000 board feet. The lumber cut for 1928 was 320,000,000 board feet, whereas consumption was estimated at 190,000,000. Even so, local material does not control the market and meets severe competition from the Pacific coast and the southern pine belt. Lumber from other regions can compete even in the face of a freight charge averaging $14 per M as against an average of $5 on home products consumed locally. This situation forces producers in the Southwest to seek markets which offer a still greater advantage in freight rates.

In 1928 Arizona shipped forest products to 23 States, consuming locally approximately 26 percent of the cut. In the same year New Mexico shipped to 25 States, consuming locally approximately 37 percent.

It is not anticipated that this situation will continue indefinitely Eventually the competition from Northwest lumber will probably be less keen than at the present time. The needs for wood by a comparatively undeveloped region such as the Southwest should increase with growing population and industry. The opportunity for the employment of labor and capital in the growing, harvesting, manufacturing, and merchandising of the forest crop is of major importance to communities near the forests. These industries also contribute in taxes to the support of county and State governments. All these and other benefits of the forest argue strongly for the continuance of these lands in timber even though it must be accomplished through public ownership. It is estimated that if all productive forest lands in Arizona and New Mexico—regardless of ownership, and eliminating those which have been devastated or which are classed as inaccessible for lumbering—were placed under management such as is now practiced on the national forests, they might yield about 300 million board feet per year perpetually. Any appreciable increase over this production would require more intensive silviculture than is now being practiced. If such an increase becomes desirable, it can probably be obtained most economically by applying intensive methods on the best and most accessible lands.

More than 90 percent of the present and future agricultural development of the Southwest is dependent upon irrigation. The limitations of this development are directly dependent upon the amount of water permanently available. The flow of water from well-managed forest areas is for the most part clear and steady, in contrast with the erratic floods of silt-laden water from more or less denuded areas.

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All the larger streams used for irrigation in this region have their headwaters in the forests. Watershed protection will be obtained automatically under good forest management.

Recreation is fast assuming a prominent place among the forest values in the Southwest. The ponderosa pine forests, in particular, delight the tourist with their open parklike spacing, the numerous secondary roads leading into out-of-the-way places, the exhilarating summer climate, and lastly, the absence of fires of such proportions as to endanger human life. Hunting and fishing attract thousands of people to the woods and are indirectly a considerable source of revenue to forest communities. Utilization of timber under good forest management is not incompatible with the preservation of recreational values.

The Black Hills is in many respects an economic unit. It is a region of forests, mines, and farms, a region comparatively rich in natural resources, surrounded for great distances by treeless plains used for little but stock raising and dry farming. It is reached by branch lines of the Chicago, Burlington & Quincy; Chicago & North Western; and Chicago, Minneapolis & St. Paul railroads. Mining is the principal industry. The Homestake Mine is the largest gold producer in the United States. The mines and railroads require a large amount of timber for stulls, ties, and lumber. The ranches and farms constitute a stable market for miscellaneous forest products. Although lumber from the "Inland Empire" and the Pacific coast competes with and helps to establish the price in the local market, it is economically much sounder that the bulk of the supply be obtained locally, and that the many small sawmilling communities be assured a permanent outlet for their products. It is probable that under good management a perpetual annual yield of at least 40,000,000 feet can be maintained in this region.

OVERHEAD EXPENSE IN LOGGING OPERATIONS

Except on small areas subject to peculiar local conditions, it is fair to say that large-scale commercial operations in virgin stands must have an average minimum cut of 5,000 board feet per acre to make operation economically practicable in any of the forest types in the Southwest. In some cases the cut runs considerably higher than this over the entire operating area. Even in the ponderosa pine type some of the very large lumbering operations count upon a cut of 9,000 to 10,000 board feet per acre and could scarcely operate if it were less. In the Douglas fir type the cut will run as high as 20,000 feet per acre, and one large concern operates in country where the cut has averaged over 18,000 feet for thousands of acres. In the Black Hills, in the pine type, the local market demands are possibly a little keener, and the situation in general is such that operation is practicable with a cut of 3,000 board feet per acre or even less.

An advance in lumber price levels would tend to increase the margin between cost of manufacture and selling price, thus permitting the higher overhead cost incident to a smaller cut per acre. It may be expected that as virgin-timber supplies decrease the selling price of good grades of lumber will increase. On the other hand, it is true that merchantable virgin stands are becoming less and less accessible, and that higher transportation costs will tend to increase production expense.

The market calls for two classes of products: (1) Lumber, and (2) ties, mine stulls, and props. The great bulk of the material goes into lumber. Trees less than 11 inches in diameter are too small to produce a standard hewn tie, but mine props are cut as short as 4 feet with a 4-inch top diameter.

RATE OF GROWTH

To produce saw logs, it is considered necessary in the Southwest to grow trees at least 20 inches d. b. h.[3] and in the Black Hills 16 inches d. b. h. Table 4 indicates that although ponderosa pine and Douglas fir may on the best sites attain a diameter of 20 inches in 100 years or even less, 140 to 180 years are required on most national forests in this region and in some instances 200 or more years. The figures in this table have not been definitely correlated as to site quality and density of stand, and for this reason are not to be regarded as a measure of differences between national forests. They do, however, give a fair indication of the range of diameter growth and the possibilities under the most favorable conditions. In the Black Hills, 16-inch trees can be grown in moderately dense stands in about 140 years. Under Forest Service methods of partial cutting it is planned in the Southwest to cut over the forest 2 or 3 times during a rotation;[4] in the Black Hills, 4 times. Without going into details as to volume yields, it is apparent that growth is generally slow and financial returns are meager in comparison with conditions in the best timber-growing regions in the United States.

TABLE 4.—*Diameter of southwestern species at different ages, in Arizona, New Mexico, and the Black Hills*

Species, national forest, and type or site	20 years	40 years	60 years	80 years	100 years	120 years	140 years	160 years	180 years	200 years
Ponderosa pine:										
Apache:	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
Type 1 [1]	2.0	4.6	7.4	9.9	12.2	14.4	16.5	18.1	19.7	------
Type 2 [2]	1.3	3.4	6.0	9.0	12.0	14.8	17.5	20.0	22.4	24.7
Tusayan	1.8	5.2	8.4	11.1	13.2	15.0	16.6	18.0	19.3	20.4
Prescott	4.0	11.4	16.8	21.0	24.0	26.2	27.6	28.6	29.4	30.0
Sitgreaves	------	------	11.2	14.7	17.7	20.2	22.1	23.8	25.2	26.4
Gila	1.0	6.8	11.2	14.8	17.6	19.8	21.5	22.9	23.8	24.7
Crook	3.0	8.1	13.6	17.7	20.1	22.6	25.2	26.7	28.4	29.5
Carson	0.7	3.1	6.5	9.3	11.4	13.0	14.3	15.6	16.8	18.1
Harney:										
Site 1	3.0	5.6	7.5	8.8	9.9	11.2	12.6	13.9	15.2	16.2
Site 2	1.9	3.7	5.5	7.0	8.2	9.3	10.3	11.0	11.8	12.4
Site 3	1.5	2.9	4.2	5.6	6.7	7.6	8.4	9.0	9.5	9.9
Douglas fir:										
Apache	1.4	3.4	6.0	9.0	12.2	15.6	18.8	22.0	26.0	27.7
Crook	1.9	8.9	13.4	17.2	19.8	22.4	25.0	27.6	30.3	31.9
Gila	------	5.2	9.0	12.6	15.7	18.7	21.5	24.5	27.2	29.0
Carson	------	2.3	4.9	7.3	9.6	11.7	13.5	15.3	17.4	20.0
White fir:										
Crook	1.8	7.0	11.2	14.4	17.8	20.2	22.2	------	------	------
Carson	------	1.7	4.2	6.9	9.1	10.9	12.2	13.5	14.8	16.2
Limber pine:										
Crook	1.0	5.0	8.7	11.5	13.7	15.5	17.0	18.3	------	------
Blue spruce:										
Apache	1.1	3.8	9.2	14.8	18.4	21.0	22.8	------	------	------
Engelmann spruce:										
Crook	------	3.0	6.6	10.2	13.1	15.2	16.7	18.3	19.8	------
Carson	------	2.1	4.9	8.3	10.9	13.1	14.9	16.4	17.7	------
Alpine fir:										
Carson	------	2.0	4.9	8.3	10.8	12.8	14.2	16.4	17.1	------

[1] Ponderosa pine type.
[2] Douglas fir-ponderosa pine transition.

[3] D. b. h.=diameter 4.5 feet above the ground, or at breast height.
[4] "A rotation is the average normal period of years required to reproduce, grow, and harvest an even-aged crop of trees in a given area of land." Chapman (*3, p. 285*).[5]
[5] Italic numbers in parentheses refer to Literature Cited, p. 80.

GRAZING ON FOREST LAND

Practically all forested land in the Southwest, irrespective of ownership, is used for stock grazing. Grazing is on a fee-per-head basis in the national forests, and generally on a lease-per-acre basis on other public land and on private land not grazed by the owners. This means an annual return to the owner averaging between 1 and 2 cents per acre, gross, on national-forest lands, and somewhat higher on Indian reservations and private lands.

TAXATION

Although it cannot be said that the present system of forest taxation has been an appreciable factor in the practice of forestry on private lands in the Southwest, experience in other regions indicates that it might prove to be a serious handicap.

OWNERSHIP

As has been pointed out, the rate of tree growth in the Southwest is very slow and financial returns are low. Large-scale railroad logging, which is the prevailing system under present economic conditions, is facilitated by extensive holdings under a single ownership. The most far-reaching economic values of forests, including watershed protection, benefit the public on a broad community basis, rather than the individual. All this points to public ownership as the most logical and practical foundation for forestry in this region. From this point of view it is, therefore, very fortunate that 88 percent of the total forest land is already in public ownership, about three-fourths of it included within national forests. The several States are practicing varying degrees of forestry on their smaller holdings. Arizona, through a cooperative arrangement with the Forest Service, has obtained the same forest practice on some 20,000 acres of land as is applied on adjacent national-forest areas. A similar agreement has been made effective with New Mexico.

Economic conditions, it is believed, will lead to the acquisition by the public, probably the Federal Government, of most of the area now in private ownership. Already various land-exchange acts permit acquisition by the United States Government of privately owned timberland within the national forests in exchange for government-owned stumpage or land, and a considerable acreage has been added to the national forests in Arizona and New Mexico in this way. Large areas still remaining in private hands within the two States unfortunately have been logged under destructive methods. Because of the great economic loss in unproductive lands and the great cost of reclaiming them, it is obviously advantageous that public agencies either acquire the timber before these lands are logged or make suitable provision to insure conservative logging, fire protection, and other measures necessary to maintain the land in productive condition.

PUBLIC SENTIMENT

Although the general public is coming to understand the importance of timber production, the indirect benefits from the forest appeal most to the average citizen.

An enlightened agricultural population appreciates the value of a forest cover in its protective influence on the watersheds from

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which domestic and irrigation water is obtained. Extensive irrigation development is dependent in great measure upon large streams such as the Gila River, Rio Grande, and Salt River. Public sentiment in irrigated sections should be an effective force in demanding conservative handling of the forest lands which affect their water sources, irrespective of ownership.

As is the case all over the country, the construction of roads and trails into previously inaccessible mountain areas in the Southwest is giving a great impetus to forest recreation. Similarly, interest in fish and game is increasing. All this develops a sentiment which, while not particularly interested in keeping forest lands productive per se, does deplore forest destruction and in many instances would go so far as to prohibit any cutting whatsoever. In any event, it favors the retention of forest lands in public ownership, subject only, at the most, to restricted cutting.

HABITS AND REQUIREMENTS OF FOREST TREES

Adequate appreciation of the forestry measures prescribed later in this bulletin can be had only through an understanding of the climatic and other conditions encountered, and of the habits and requirements of different tree species. Other publications (*1*, *11*, *12*) treat these subjects more fully, and therefore only the most salient features will be discussed here. The greater portion of the region is characterized by low annual precipitation and sharp seasonal and annual variations in its distribution. In the lower altitudes of the Southwest, protracted droughts accompanied by high winds in early summer and in autumn are trying on vegetation. Fire hazards are also high during these seasons.

Drought alone is usually thought to account for the slow growth and restricted occurrence of trees in the Southwest. Low temperature, however, is also a limiting factor. Trees whose heat requirements are relatively high, such as ponderosa pine, are found in middle altitudes which, as compared with higher levels, have a warm, dry climate. Ponderosa pine would produce much heavier stands at altitudes above 9,000 feet, where the precipitation is around 30 inches, but for the fact that the temperature is too low. Ponderosa pine is here replaced by Douglas fir and white fir, both of which have lower heat requirements and higher moisture requirements.

Since temperature and precipitation are influenced in opposite directions by elevation (fig. 2), especially favorable conditions with respect to the two factors seldom coincide. As one factor approaches the optimum for a given species, the other becomes limiting. This relation governs the distribution of species and causes the forests to be divided into well-defined altitudinal belts or zones, known in forestry as forest types. In the Southwest the main forest types, in order of altitude, are pinon-juniper or woodland, ponderosa pine, Douglas fir, and Engelmann spruce. The woodlands, though of considerable local importance for fuel and fence posts, yield no saw timber and are not regarded as coming within the scope of this bulletin. Of the three saw-timber types, ponderosa pine occupies the lowest, warmest, and driest zone, Engelmann spruce the highest, coldest, and wettest, and Douglas fir is intermediate.

Figure 3 shows the monthly temperature and precipitation by forest types in northern New Mexico. Corresponding graphs for

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Arizona and the southern Rockies are very similar, except that in Arizona the winter precipitation is higher and the May-June precipitation lower. In the Black Hills the May-June precipitation is higher and the July-August precipitation lower than in the Southwest.

PONDEROSA PINE TYPE

GENERAL FEATURES

Because the ponderosa pine type contains 85 percent of the saw timber and is the most accessible, it is by far the most important type

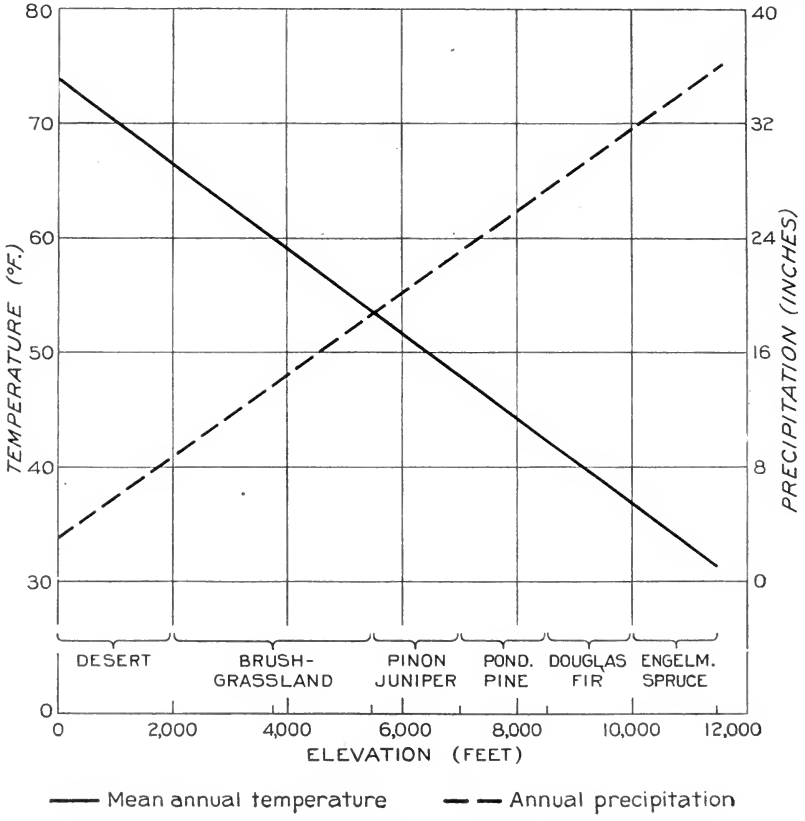

FIGURE 2.—Temperature and precipitation in relation to altitude in Arizona.

in the region from the standpoint of timber production. The optimum altitudinal range in the Southwest is from 7,000 to 7,800 feet. At the lower limit it grades into woodland, and at the upper limit and in other moist, cool situations, there is an admixture of Douglas fir, white fir (*Abies concolor* Lindl. and Gord.), and blue spruce (*Picea pungens* Engelm.). In the Black Hills the pine is usually in pure stands but over limited areas occurs with a light mixture of white spruce (*P. glauca albertiana* (S. Br.) Rehd.). Because of the northerly latitude of the Black Hills, the altitudinal occurrence is relatively lower, but the range is greater, extending from 3,500 to 7,200 feet.

This type is characteristically a pure stand of ponderosa pine and occurs as extensive uniform bodies, unbroken except for occasional

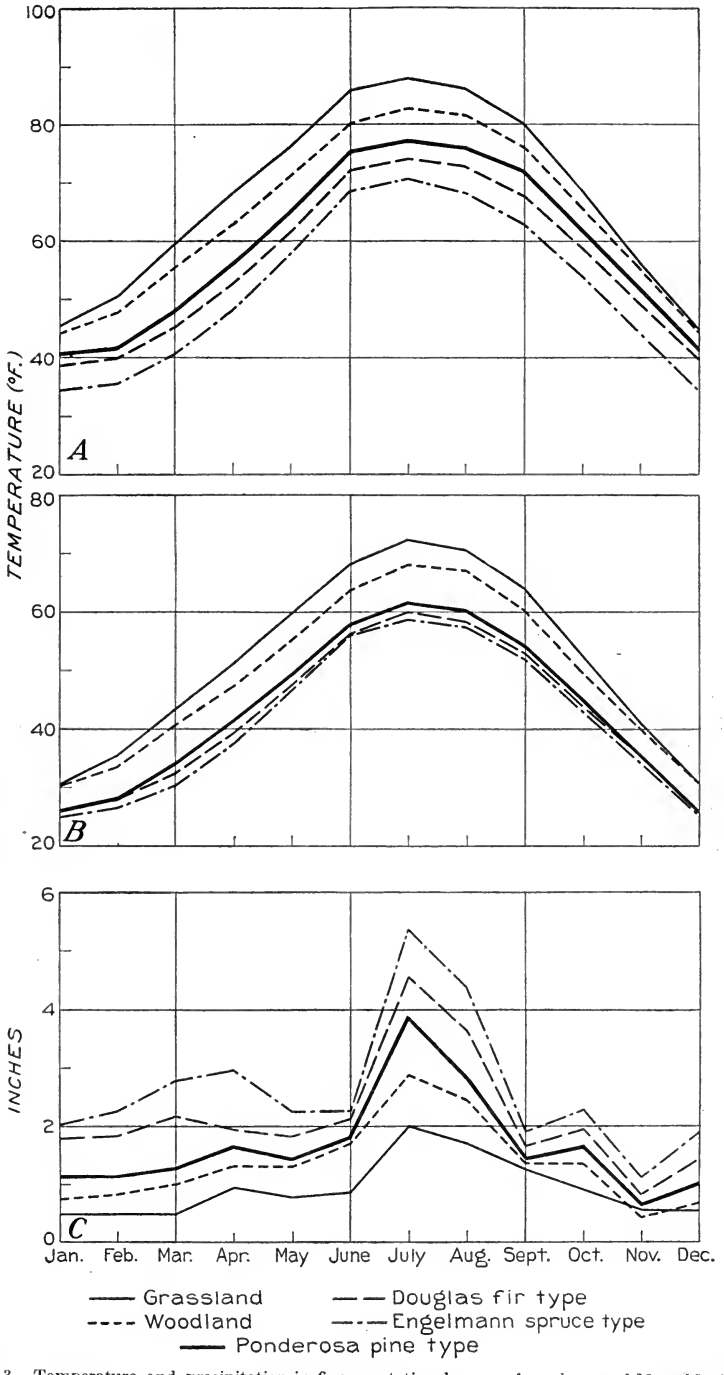

FIGURE 3.—Temperature and precipitation in five vegetational zones of north-central New Mexico: *A*, mean maximum temperature; *B*, mean temperature; *C*, precipitation.

openings known as parks or prairies. The best large body of ponderosa pine timber is on the Sitgreaves National Forest, where the total stand of 4 billion board feet averages 10,000 feet per acre. On the Coconino National Forest it averages about 7,000 feet per acre; in northern New Mexico, Colorado, and the Black Hills, from 4,000 to 6,000 feet.

Ponderosa pine differs widely in density and other features in various parts of the region. In the Black Hills are dense stands of slender trees which reach maturity in about 140 years. In northern Arizona (fig. 4) the stands are typically open, many-aged and strongly grouped, but individual trees grow to larger size than in the Black Hills. From 150 to 200 years, depending upon the site and the size desired, are required to produce saw timber. The southern Rockies

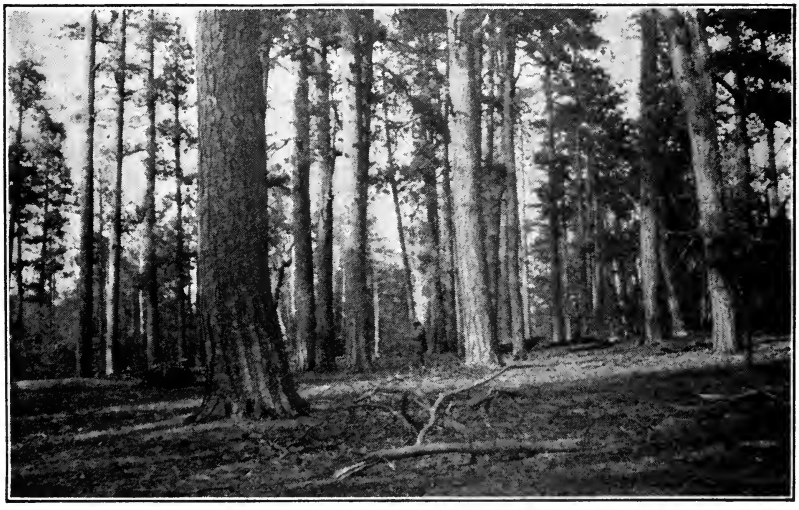

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FIGURE 4.—Mature stand of ponderosa pine on the Colorado Plateau. Small areas yield as high as 40,000 board feet per acre, and blocks of many square miles will average 15,000 to 20,000 feet per acre.

present conditions intermediate between the above extremes of density, distribution, size, and age (fig. 5).

Changes in the physical appearance of ponderosa pine correspond with three broad age classes that are so universally recognized in cutting practice and silvicultural work generally as to deserve formal definition. Trees of 200 years and older are characterized by a deep yellowish or cinnamon-brown bark and a more or less flat top, and are known as "yellow pines". Those of 150 years and less have a dark, nearly black bark and a round or pointed top; these are "blackjacks". Between these two classes are the "intermediates", having a bark less definitely brown than the yellow pines—often brown on one side of the bole and black on the other—and with a rounded top tending to flatten out.

IMPORTANCE OF NATURAL REPRODUCTION

Natural reproduction is essential both as a means of restocking cut-over or burned lands and as a means of replacing the trees which die in virgin forests. Artificial reforestation is generally so expensive

as to be prohibitive, whereas natural reproduction costs nothing except for protection and, on cut-over areas, a nominal investment in seed trees.

Ponderosa pine seedlings do not thrive under a dense crown canopy, but mature uncut pine stands are usually open enough so that seedlings can grow among the old trees. Such seedlings are termed "advance reproduction" since, when the area is logged, they represent the nucleus of a new timber stand already established. In pine forests which have received adequate protection against fire and overgrazing, advance reproduction is the rule rather than the exception. It is seldom that trees of merchantable size occupy more than half of the ground area; this is because the forests are usually made up of trees of different ages and the older ones are continually dropping out as a result of

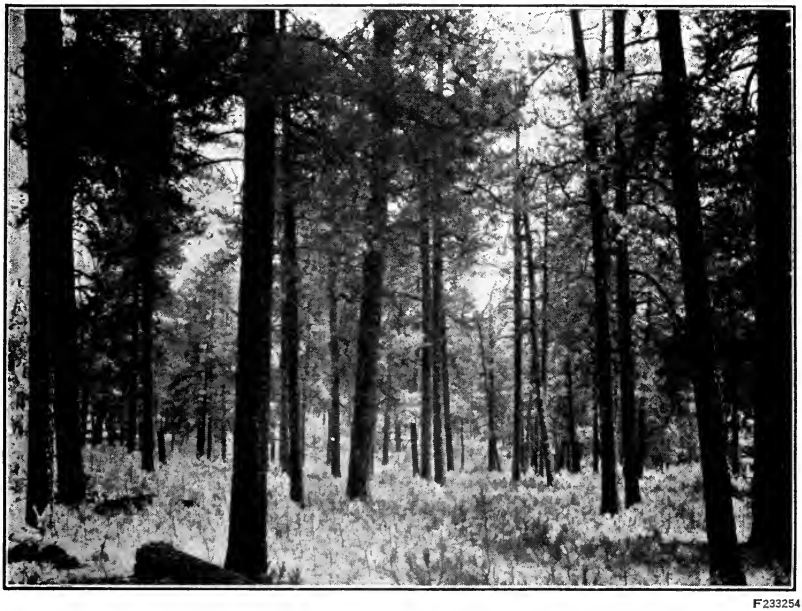

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FIGURE 5.—Type of ponderosa pine stand common in New Mexico and Colorado. The trees are of rather small size and are more uniformly distributed than on the Colorado Plateau. Seedlings grow almost under the old trees.

windthrow, lightning, fire, bark beetles, and other causes. By this process of attrition, "holes" are formed in the crown canopy, ranging all the way from a small plot where a single tree has died up to a half acre or more. If complete protection has been provided, the openings thus formed should be occupied by young trees ranging all the way from the seedling stage up to merchantable size. Since, however, few areas have escaped fires over long continuous periods, advance reproduction, if present, is likely to be confined to one or a few age classes. Even where advance reproduction is complete, however, logging will usually leave the land incompletely stocked because some of the young growth will be damaged. Occasionally there may be patches of timber too dense for seedlings to persist beneath; this condition is especially prevalent on the Colorado Plateau where the trees occur mainly in dense, even-aged groups. When cut clean, these leave unstocked spaces from 100 to 300 or more feet in diameter.

Reproduction requires attention throughout the region, and under conditions where external factors interfere too much with natural processes, obtaining it may become a serious problem.

Investigations covering a long period have determined the vital factors and remedial measures concerned in the reproduction of ponderosa pine in northern Arizona (*10*). These findings apply in a broad way to the Southwest wherever conditions are such as to present a reproduction problem. The principal factors are climate, soil, ground cover, seed supply, cutting, slash disposal, rodents, grazing, and fire.

INFLUENCE OF CLIMATE AND SOIL

From the standpoint of forest reproduction, the outstanding climatic feature in the Southwest is the drought period extending through May and June and often to the middle of July. Before this period, in the spring, the soil is moist enough for germination but the temperature is too low. By the middle of May, when the temperature would permit germination, the topsoil has become dry and the seeds lie dormant until the arrival of the July rains. If the rains are copious, germination is prompt and vigorous, but if they are deficient, or of short duration, few seeds germinate and the seedlings that do appear almost invariably die at once. Even with August rains, a secondary drought in September and October sometimes kills large numbers of newly germinated seedlings, and ground-heaving during late fall and early spring adds to the mortality. But the protracted drought of early summer accounts for by far the greatest losses. In Colorado and northern New Mexico the early-summer drought is less pronounced, but here winter killing becomes an important factor. On the whole, the reproduction problem assumes most serious proportions in the sections having a distinctly dry early summer.

Other conditions tend to aggravate the effects of deficient precipitation. Foremost among these are a clay soil, the presence of deep surface layers of volcanic cinders, and luxuriant ground vegetation.

Clay soils are unfavorable to reproduction of ponderosa pine because of their compact structure, which impedes root development and is relatively impermeable to moisture and air. These characteristics are accentuated by trampling of livestock and by logging operations in wet weather. On soils classed as clay loams reproduction is difficult to establish, but when good stocking has been attained heavy stands of timber have resulted. Even planting does not always succeed. A mixture of organic matter, gravel, and stones renders clays more hospitable to young trees. A light cover of leaf litter or herbaceous growth is also beneficial in alleviating the packing and baking tendency of bare clay soils.

Cinder soils represent the opposite extreme in structure and texture. They drain too rapidly and become so dry on the surface that germination cannot take place unless showers occur almost daily. A covering of litter, pieces of wood, or living vegetation is helpful, but rather inadequate. Where cinders are underlain by clay or loam, trees usually make excellent growth once the roots reach these heavier layers. Sandy or gravelly loams represent intermediate conditions between clay and cinders, and they are the best soils for both reproduction and subsequent timber growth.

Ground vegetation acts in two opposite directions. It tends to temper high extremes of heat and drought on the soil surface; it

retards run-off, promotes penetration of water, and lessens frost heaving, which is responsible for wholesale seedling losses on bare soils of heavy texture. But after the first few weeks the seedling is no longer dependent upon surface moisture and is less subject to injury by high surface temperature. As the roots penetrate the upper few inches of soil, they come in direct competition with the roots of the grasses, weeds, and bushes which sheltered the seedlings in their infancy. The young pine needles now reach out for sunlight which they need in order to perform their function of manufacturing food for the plant. If the ground vegetation is tall and dense, it becomes distinctly harmful by robbing the seedling of soil moisture and sunlight (*15*). The forester should aim to obtain the early benefits of ground vegetation without too much of its harmful influence in the later life of the seedling. This object can be accomplished in some measure by carefully regulated grazing.

Standing trees act in much the same way as ground vegetation, but their influence is greater. Tree shade favors germination and early survival of seedlings by checking excessive evaporation and high temperature at the surface of the soil. This effect is enhanced by the presence of litter. On the Colorado Plateau very young seedlings are more numerous in the shade zone than in the open, but mortality is high in dense slash, and after 2 or 3 years the surviving seedlings are noticeably undersized. That this effect is not due mainly to root competition from the older trees, as is often asserted, is indicated by the fact that soil moisture remains higher throughout the driest part of the summer in the zone of densest shade and litter than in the open. Herbaceous vegetation, particularly of the grasses which flourish in the sun, has the same undernourished appearance in the shade as do the pine seedlings. The trouble is usually considered as due to deficient light, but heat is as important as light for photosynthesis, or more so (*13*). In either case it is evident that ponderosa pine seedlings require a large amount of direct sunlight for normal development. If the old trees occur sparsely or in fairly open stands, seedlings grow almost under the crowns; but if the old trees are in groups, particularly in a cold climate, large spaces underneath and to the north of the groups remain practically bare of seedlings.

INFLUENCE OF SEED SUPPLY

An adequate supply of seed is obviously of prime importance. In the Southwest ponderosa pine seeds seldom lie over from one year to the next. Good seed crops occur only at intervals of from 2 to 5 years. Reproduction is dependent upon the coincidence of seed crops and abundant, well-distributed precipitation over at least 1, and preferably 2 years. Since both seed crops and rainfall are more or less erratic, the element of chance governs to a large extent. Although this uncertainty cannot be eliminated, it can be lessened by providing enough seed trees so that when natural conditions are favorable the supply of seed will be sufficient.

Estimates based upon results of broadcast sowing, together with calculations of the volume of seed production in years of good reproduction, have placed the minimum seed supply for the Southwest at approximately 8 pounds per acre. Assuming an average yield of 2 pounds per tree, this would call for four seed trees. In practice, the

yield of the average seed tree is less than 2 pounds and much of this is sure to be consumed by rodents. Therefore, when specifying that four seed trees per acre are required, it is assumed that a considerable additional quantity will be contributed by young trees too small to be rated as effective seed bearers.

Fairly large trees are usually required to produce seed in adequate quantities. Although trees down to 10 or 12 inches in diameter are often described as "loaded" with cones, actual measurement of the yields has shown that the quantity is small as compared with that of large trees. Moreover, only a small proportion of the trees in the lower diameter classes are cone bearers. A comparison of yields of 100 trees felled in 1913 (*10*) gave the average number of pounds of seed per tree for different diameter classes as follows: 12- to 18-inch trees, 0.44 pounds; 18- to 24-inch trees, 1.19 pounds; 25- to 30-inch trees 1.37 pounds; trees over 30 inches, 1.28 pounds. Germination tests have given somewhat higher values for immature than for mature trees, but the difference is not consistently great enough to warrant recognition. The minimum diameter limit for effective seed production in the Southwest, which varies somewhat with the character of the stand and the locality, has been placed rather arbitrarily at 21 inches, although in New Mexico and southern Colorado where the trees are more numerous and a smaller quantity of seed appears to be needed for reproduction, the limit might be lowered to about 19 inches. Theoretically, it is possible to leave enough small trees to produce the required volume of seed, but this does not always work out well in practice because, while such trees may be sufficient in number, they may occur in large groups. Under these circumstances, a large proportion of the seed falls directly under or near the tree groups where seedlings cannot grow, and relatively little reaches the clean-cut areas to be restocked.

Of no less importance than the size of the tree selected as a seed bearer is its physical condition. Mechanical injuries to the bole apparently do not lower the seed yield, but rather pathological agencies, such as mistletoe and leaf diseases. There also appear to be inherent differences in fruiting capacity which cannot be explained by the character of the crown or foliage, but are indicated by the quantity of old cones on the ground, representing the production in several seed years. It is obviously important to select trees which may be expected to live and bear seed through the reproduction period, and which will grow. Trees over 25 inches or so in diameter are more subject to windfall and lightning than smaller ones and they involve a greater risk of wood capital in proportion to seed yield.

Considering all aspects, the ideal seed tree in the Southwest may be described as a sound, thrifty, large-crowned, well-formed tree, usually between 20 and 25 inches in diameter at breast height, and showing evidence of having borne good seed crops in the past (fig. 6).

In the Black Hills, seed trees as such are rarely needed; where they are needed, trees about 14 inches d. b. h. will usually suffice.

EFFECTS OF CUTTING

Cutting, with its direct and indirect consequences, is the most potent silvicultural agency within the direct control of man. Its direct effect in the removal of seed trees has already been discussed. However, where advance reproduction is present and ample, only 1 or

2 seed trees per acre are needed, their function being to seed up blank spaces caused by logging operations and also the usual stump patches resulting from the cutting of large groups of trees.

As may be gathered from the discussion of advance reproduction (p. 14), the presence and condition of such reproduction should be a prime consideration in cutting. The removal of trees from a stand exercises a strong influence upon moisture, light, and temperature, as has already been seen. When a tree is felled, the soil moisture formerly taken by its roots immediately becomes available to other plants. Neighboring trees usually respond by increased growth. Pine seedlings thrive in these vacated spots if they can become established ahead of other vegetation. The desirability of cutting at a time when young seedlings are on the ground under the trees and before they become suppressed is obvious.

Where advance reproduction is absent, unless pine seedlings become established soon after cutting, weeds and grass may take possession to the exclusion of the pine. Where there has been a prompt response, young ponderosa pine seedlings that pass the first season are benefited by the sunlight admitted by removal of overhead cover. This opening up of the stand may, however, be to the detriment of such species as the firs and spruces. A knowledge of the response of different species to insolation and evaporation makes it possible to employ cutting as a means of controlling the composition of the stand.

F161983

FIGURE 6.—A good seed tree in the foreground. The full crown carries a large leaf area and the pointed top indicates good height growth. The smaller trees in the group to the left bear only small quantities of seed. The large tree in the right background is declining and should not be left for seed.

From the foregoing it is clear that cutting properly timed with reference to seed crops and seedlings already on the ground, and properly regulated with reference to selection of trees to be removed or left, not only permits but distinctly favors natural reproduction. In a fully stocked stand of ponderosa pine, reproduction of this species is impossible without cutting. It is only as surplus soil moisture and adequate insolation become available that seedlings can grow. In nature, these conditions are brought about by the death of old trees; under management, the same effect can be brought about by cutting.

EFFECTS OF SLASH DISPOSAL

One of the inevitable consequences of cutting is a mass of debris or "slash" consisting of tops and branches which have not sufficient value to warrant their removal from the woods. The most obvious objection to slash is that it is a fire menace. Slash fires usually kill all young growth and many old trees. For this reason it is desirable, if the fire hazard is great, especially where advance reproduction exists, to burn the slash under control when weather and other conditions are such that little damage will result.

There are, however, many other angles to the slash question—so many that generalizations must be used with great caution. Whether the presence of slash is intrinsically detrimental or beneficial to forest reproduction depends on many circumstances. Among the factors

F161979

FIGURE 7.—Pulling slash—the tops have been pulled away from seed trees, but in most instances they are still too close for fire protection.

to be considered, aside from fire hazard, are the density and age of the slash, herbaceous vegetation, soil, topography, and grazing. Methods of disposal that do not involve burning the slash are shown in figures 7 and 8.

Slash may also have important silvicultural effects through its influence upon soil conditions. A layer of slash so deep and dense as to cover small seedlings and prevent seeds from reaching the soil is obviously undesirable. After such masses have broken down, however—a matter of 10 to 15 years or even more—seedlings may gain a foothold and once established make rapid growth because of the good moisture conditions created by the soil mulch and the absence of competing plants. Eventually the rotted slash adds some organic matter to the upper layers of the soil, but this is a slow process, and the contribution of nitrogen is much less than is generally supposed.

If the ground is occupied by dense, rank-growing grass, such as Arizona fescue (*Festuca arizonica*), a moderate application of slash

stimulates the grass at the expense of the young tree seedlings, with the result that the seedlings are likely to be killed by excessive root competition and shade. This effect was clearly evident in the big seedling crop of 1919. If the slash is dense enough to kill the grass, the effect is ultimately beneficial.

On bare soils which are either very fine and compact or very coarse, a moderate cover of slash has proven decidedly beneficial in aiding the establishment of seedlings. The benefits here are clearly in aiding percolation of water and in moderating the high surface temperatures and extreme desiccation which result when such soils are exposed to the direct rays of the sun. Seedlings which gain a foothold in brush-mulched soils devoid of other plants usually make extremely rapid growth. A slash cover helps to check run-off from heavy rains, which

F17010A

FIGURE 8.—Lopping and scattering slash. In the present state the soil cover is too dense for good germination, but after the branches break down seedlings can start. The soil is well protected against erosion if grazing is not too heavy in the open spaces.

would carry away the rich surface layers and form gullies; but as a rule, slash alone should not be relied upon to stop erosion, since it is seldom adequate in quantity to cover all the ground surface. Rather, it should be scattered in denuded spots to supplement natural cover.

Another important benefit of slash is that the seedlings which come up in it are protected during infancy against grazing damage. It is quite common on overgrazed cut-over areas to find that almost the only remaining seedlings are in old top slash (fig. 9). The explanation formerly given for this was that slash created favorable conditions for germination. Investigations on the Colorado Plateau in 1920 and 1921, however, showed that usually more seedlings actually started in the open than in slash, but that most of those in the open were killed wherever grazing was heavy, whereas those in situations protected by slash remained unharmed (*10*). Although these seedlings became exposed to browsing as they grew up through the branches,

they had by that time passed the stage in which browsing is directly fatal.

The favorable and unfavorable effects of slash may be summarized as follows: It favors absorption of water, decreases evaporation, tempers extremes of heat, adds organic matter to the soil, retards run-off, and protects young seedlings from browsing by livestock. On the other hand, it increases the fire danger, it favors the increase of injurious rodents, it may cover seedlings or hinder germination, and it may encourage the growth of coarse grasses at the expense of tree seedlings. Whether the benefits will outweigh the unfavorable effects or be outweighed by them on a given area can be predicted only by carefully considering all the factors involved and their relative importance on that particular area.

F249280

FIGURE 9.—Pine seedlings which have survived overgrazing because they were protected by logging slash in their infancy. Grazing damage has been light in more recent years.

EFFECTS OF GRAZING

On extensive areas, particularly in northern Arizona, ponderosa pine reproduction is known to have been arrested for many years by adverse grazing influences. Since 1926 the situation has been greatly improved, mainly as a result of lighter stocking, improved distribution, and a shortening of the grazing season. The most significant facts developed in dealing with this problem are briefly as follows:

(1) Overstocking is the primary but not the sole cause of damage to forest reproduction.

(2) Ponderosa pine seedlings less than 3 years old are the most susceptible to fatal grazing injury.

(3) Both cattle and sheep may do severe damage, though usually under somewhat different conditions.

(4) Under conservative grazing, most of the damage occurs in early summer and in the fall, being relatively light in midsummer.

(5) Grazing can be directed in such manner as not only to decrease damage to a negligible figure, but also to aid the establishment of pine seedlings.

It is axiomatic that if a tendency exists for livestock to eat pine seedlings, two animals will do more damage than one. If there is a shortage of forage, the amount of damage may increase out of all proportion to the number of animals. On many livestock allotments of the Coconino, Kaibab, and Sitgreaves National Forests, the stocking after 1926 was only from 50 to 75 percent of that which prevailed before 1926. By 1929 the effect of these reductions on seedlings had become very marked. On an extensive series of plots current damage to 80 to 100 percent of the seedlings before 1926 was reduced to a negligible percent by 1929. Shortening the grazing season and obtaining better distribution played their part, but these are, in effect, merely forms of reduced stocking. That damage generally has persisted on areas of concentration while virtually disappearing from most areas of lighter use points to overstocking as a major factor. Certain areas on which conservative stocking and good management as regards forage have not done away with excessive damage to tree seedlings—although they are the exception rather than the rule—indicate that under certain conditions good range management may have to be supplemented by additional safeguards if damage to forest reproduction is to be kept under adequate control.

Investigations following the abundant pine germination of 1919 on the Colorado Plateau have shown that the first 2 or 3 years in the life of the young pine seedlings are the most critical (*14*). Unless grazing is very heavy, few seedlings are touched during the first year, evidently because most of them are at that time too small to attract livestock. In the second and subsequent years, however, great numbers may be eaten. In 1920, it was not uncommon to see large patches on which nearly every seedling of the 1919 crop had been bitten off or defoliated so severely as to preclude recovery. Contrary to the usual impression, most of the direct damage is done by biting rather than trampling. The reason for the large proportion of fatalities in the second year after germination is that in this stage the seedlings are usually small and relatively succulent; the entire crown may be bitten off or all the leaves may be removed, leaving a bare stem which almost invariably dies. After the plants become older and more woody, they are eaten down less severely and a few of the lower leaves are likely to escape. In this condition they have a chance to recover. Records on several thousand seedlings under many conditions between 1919 and 1929 showed that although during the first year after germination usually less than 10 percent were bitten, nearly all of these were killed outright. In the second season, on heavily grazed areas, from 40 to 60 percent of the remainder were killed outright and from 20 to 30 percent of the survivors were injured. After the second year the percentage killed fell off sharply, but the percentage injured rose and accumulated until by 1924 only about 30 percent of those living had escaped serious injury (fig. 10), and these were mostly in situations where protection was afforded by rocks or logs. Under the much lighter grazing that has prevailed since 1926, relatively few small seedlings have been killed by browsing.

The fate of injured seedlings depends upon many circumstances, such as age and inherent vigor, environment, and finally upon the

frequency and severity of subsequent injury. Other things being equal, the older and larger the seedling and the more foliage left after the first injury, the better are its chances for survival. Favorable soil and general growing conditions greatly improve the chances for survival. If the seedling is severely browsed year after year, ultimate death is certain; but if browsing is intermittent or light enough so that a considerable amount of foliage remains, the seedling may persist indefinitely although making little growth. It was formerly thought that pine seedlings which had been thus deformed and impoverished could never recover even if no longer subjected to browsing. In recent years, however, it has been found that they have a remarkable capacity for recovery, once the damage is discontinued. A few years are required to develop an effective leaf

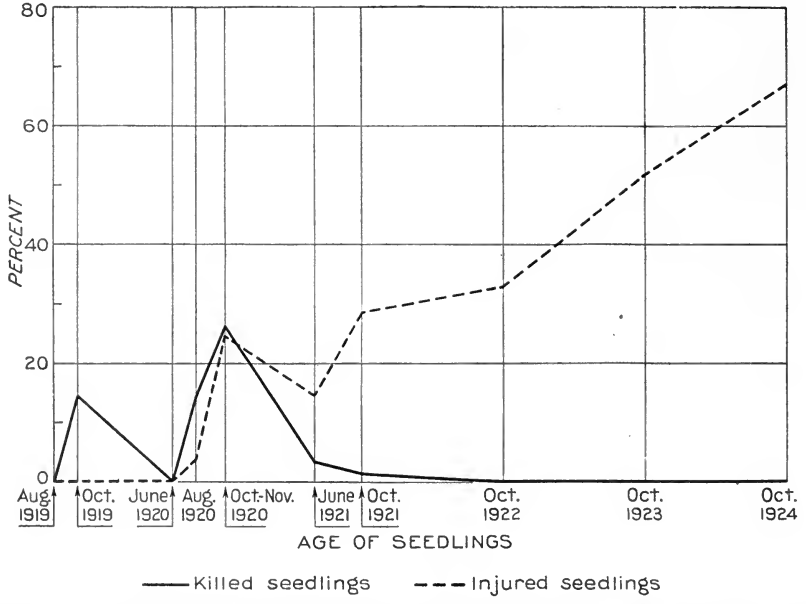

FIGURE 10.—Intensity of grazing damage as related to age of ponderosa pine seedlings germinated in 1919, as shown in percentages of seedlings present at each examination. Injured seedlings are cumulative after June 1921.

area, and then a leader emerges which usually grows at a phenomenal rate (fig. 11).

Until recent years it was thought that cattle were responsible for relatively little damage as compared with sheep. Since prior to 1926 both cattle and sheep generally grazed on the same ranges in localities where damage was prevalent, it was difficult to fix the responsibility as between the two classes of stock. During this period, however, it was widely observed that where reproduction had failed on the open range under dual use, it was almost without exception progressing satisfactorily in adjacent cattle pastures to which sheep did not have access. Many striking examples of this kind are on record. Examples have also been cited in which restocking on the open range was attributed to the absence of sheep during the early life period of the seedlings (*10*). The widespread destruction of

small seedlings by browsing under dual use, as recorded on the Coconino, Kaibab, and Sitgreaves in 1920, was negligible in cattle pastures, although older seedlings were sometimes damaged in such pastures. The evidence, though indirect, pointed to sheep as the primary agency in destroying small seedlings. In 1926 cattle were segregated from sheep, and at the same time both classes of stock were greatly reduced in number. Damage, though perceptibly decreased, continued on cattle ranges as well as sheep ranges. But by this time the 1919 seedlings were 7 years old and thus past the critical stage. Seedlings which came up in 1928 and subsequent years suffered but few fatalities from browsing on either cattle or sheep range. This indicates that under conservative grazing small seedlings are in little danger of extermination by either sheep or cattle, even though older seedlings may be subjected to considerable damage. But no evidence has been brought forth to refute the earlier conclusion that heavy sheep grazing was primarily responsible for the wholesale destruction of second-year seedlings in 1920 and earlier periods; nor has any other explanation been offered for the striking contrast between dual use ranges and cattle pastures, which remains in evidence today on the Coconino and Kaibab National Forests.

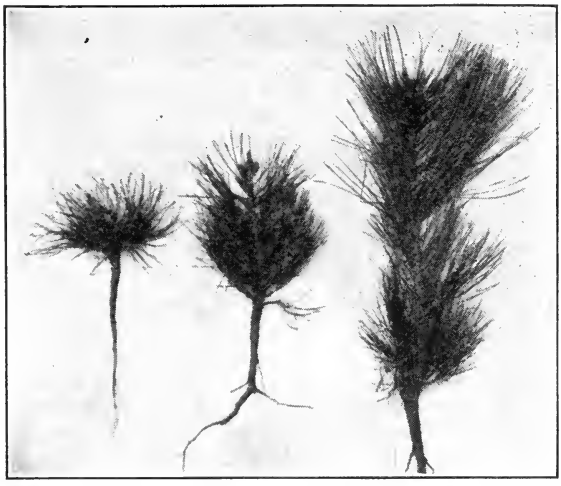

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FIGURE 11.—Pine seedlings in different stages of recovery from grazing damage. All are of 1919 germination and were subjected to severe damage between 1920 and 1926. The one at the left still has no leader but has developed a dense mass of leaves. That the other two have but recently emerged from this condition is evidenced by the dense mass of needles and fine branchlets and the pronounced bend in the main stem near the ground line.

Hill's (*5*) investigations between 1910 and 1917 indicated somewhat more damage at the height of the dry season of June and early July and also in the autumn than during the summer rainy season. In the light of later experience, the absence of clear-cut seasonal differences may be attributed to the fact that at the time of Hill's investigations and up to 1926 overgrazing was generally so extreme and widespread as to mask the effect of other factors. Under the more conservative grazing of recent years, seasonal variations in the extent and degree of damage have become very outstanding. This is true particularly of damage to the terminal shoots or "leaders", which is at its worst in the latter half of June and practically ceases after July 15. Except under extreme overgrazing, pine shoots are not eaten after they become woody, which normally occurs early in July. The time when they are most readily eaten is when they are growing vigorously, usually from about June 10 to July 5, varying with the

year and the locality. This period is coincident with the period of the grazing season when green forage is at a minimum, which doubtless is a contributing factor. Young seedlings grow through the summer and thus are an exception to the rule. After the second year, terminal growth usually ceases in July, but vigorous specimens, even in the sapling stage, occasionally make a short second growth after the summer rains get under way. Pine needles are not browsed to any great extent after their first season except under very heavy grazing. Needle browsing on current year's shoots usually begins about August 1 and increases during the fall months. Unless it approaches complete defoliation or is repeated year after year on the same tree, the effects are not serious. Unfortunately, however, there is a tendency for repetition of damage on the same areas. Leader damage not only retards height growth, but also tends to deform the young tree. After seedlings are 5 or 6 years old they have an amazing capacity for replacing lost leaders, but repeated damage of this class results in crooked stems and excessive development of side branches. Aside from the susceptibility of young seedlings to summer damage due to prolonged growth, the usual seasonal occurrence of both leader and needle browsing suggests the possibility of eliminating most of the damage by seasonal curtailment of grazing.

Under most conditions, conservative grazing as contrasted with heavy grazing favors forest reproduction, but there are some important exceptions to this rule. Wherever herbaceous vegetation grows tall and sufficiently dense to shade most of the ground, it handicaps pine reproduction by competing for moisture and light. In the Southwest, bunch-grass associations dominated by Arizona fescue (*Festuca arizonica*) furnish a characteristic example. Mountain muhlenbergia (*Muhlenbergia gracilis*) is less objectionable because it seldom attains the density of Arizona fescue, and, unlike the fescue, it makes but little growth during the critical dry season of early summer. Even the Black Hills region has its sites on which pine reproduction is handicapped by a tall, dense grass cover. In northern Arizona, records of the 1919 seedling crop (*10*) proved beyond question that luxuriant stands of bunch grass interfered with pine reproduction (fig. 12). These records also showed that whereas browsing by livestock was responsible for the death or injury of numerous seedlings, the seedlings in many instances owed their existence to heavy grazing which cropped the bunch grass close to the ground. Even more positive evidence is furnished by an experiment on the Kaibab, started in 1928, in which rodent-protected plots in nearly pure Arizona fescue were seeded to ponderosa pine and periodically clipped to various heights or entirely denuded of grass (*15*). In both number and size of seedlings surviving at the present time, the plot clipped to 6 inches is far superior to the untreated plots, the 2-inch clipping excels the 6-inch clipping, and the denuded plot outranks all others so far that it must be placed in a class by itself. These results are corroborated by natural reproduction originating in 1928 and 1929 on neighboring bunch-grass land. Where Arizona fescue approaches a virgin state, seedlings of the 1928 or 1929 classes are very scarce; but where the grass is of less than 0.1 density, or where it has been replaced by a sparse growth of weeds, seedlings are usually present in gratifying numbers. (Areas of the last class are usually devoid of 1919 seedlings because they were mostly killed

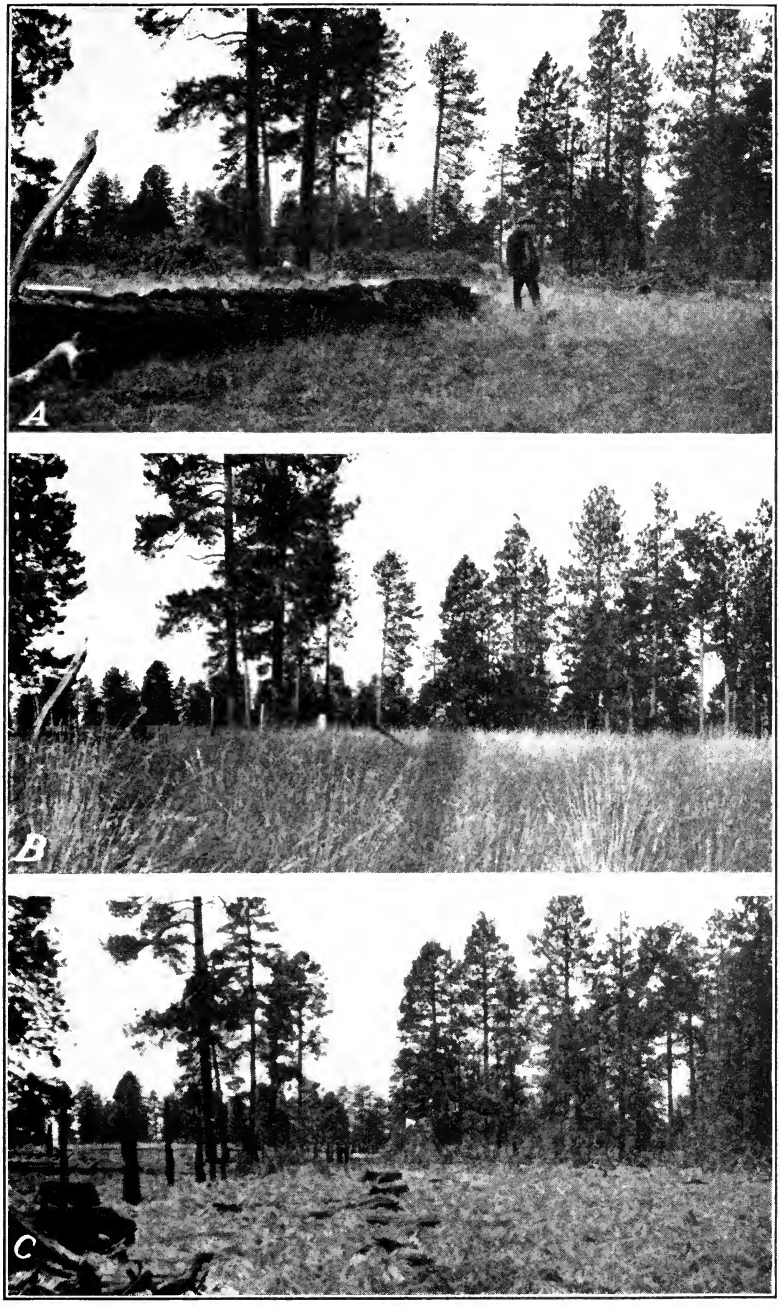

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FIGURE 12.—Opening in ponderosa pine forest after logging: *A*, Immediately after logging (1909); ground occupied by Arizona fescue, no advance reproduction. *B*, Five years later; area fenced, no grazing, grass very luxuriant, no reproduction. *C*, Twenty years after cutting; still no reproduction in the dense grass, matted down by preceding winter's snow, but good reproduction appears where grass was of only moderate density and luxuriance.

by grazing in 1919 and 1920.) Sites comparable to the denuded plot in the 1928 experiment are practically nonexistent, because where the grasses were removed by overgrazing or logging they have been almost invariably replaced by weed growth, which with pine litter and logging slash usually provide somewhat of a soil cover. Absolutely bare soils occur only in roadways or on occasional small spots where removal of the topsoil has rendered the site inhospitable to any form of vegetation. Because of invasion by plants unpalatable to livestock, only the most extreme and prolonged overgrazing results in denuding pine-bunch-grass sites. Ultimate recovery of such sites must await the establishment either of bunch grass or of pine-seedlings in sufficient numbers to form a continuous needle litter. If Arizona fescue takes possession first, the chances for pine reproduction are greatly decreased.

Although overgrazing bunch grasses to the point of denuding the soil is not advocated, grazing that keeps them down to a height of 6 inches will encourage pine reproduction and at the same time lessen the fire danger which is a threat to young pine stands in the bunch-grass type. Reduction of bunch grass to height and density favorable to pine reproduction, without excessive damage to already established seedlings, can probably be accomplished by heavy stocking with cattle during the summer rainy season and through September, accompanied by exclusion or adequate restriction during the early-summer dry season.

DOUGLAS FIR TYPE

GENERAL FEATURES

The usual altitudinal range of the Douglas fir type in the Southwest is from 8,000 to 9,500 feet. Douglas fir is the dominant species, commonly occuring in mixture with white fir and limber pine (*Pinus flexilis* James) or Mexican white pine (*P. strobiformis* Engelm.). The type is found on moister, cooler sites than the ponderosa pine type, and on drier and warmer sites than the Engelmann spruce type. There is more or less intermingling with ponderosa pine in the lower and with Engelmann spruce in the upper altitudinal range. Douglas fir forests are generally denser than the pine forests. It is probable that on the best sites this type can be made to produce saw timber in from 120 to 150 years. Maximum yields are found in the Sacramento and Graham Mountains where large areas run from 20,000 to 30,000 board feet per acre, and selected areas as high as 50,000 feet. In northern New Mexico and Colorado, the yield averages much lighter. Mature Douglas fir forests are chacteristically more patchy than those of ponderosa pine, being broken up by burned areas usually grown up to aspen (*Populus tremuloides aurea* (Tid.) Dan.).

IMPORTANCE OF NATURAL REPRODUCTION

The problem of restocking in the Douglas fir type is very often solved by the presence of advance reproduction; all species in this type except ponderosa pine are fairly tolerant of shade. Under such conditions fire protection becomes the primary consideration. As in ponderosa pine stands, the preservation of a growing stock made up of thrifty young trees is of great importance. In a fair proportion of the Douglas fir type, there are sufficient trees below 16 inches in diameter

to form a satisfactory growing stock. Unrestricted tie and prop cutting removes too many of the larger trees of this class, and if the operations are repeated devastation will be the ultimate result.

Where advance reproduction does not exist at the time of logging, the problem of restocking demands serious attention. Such is often the case in the heaviest stands in the border subregion. The requirements for reproduction of Douglas fir, the most important species of the type, have not been fully determined. It is known, however, that seed trees are indispensable and that the density of the crown canopy and the character of the seed bed are important factors.

Although seed production has not been studied in the same detail for Douglas fir as for ponderosa pine, it is evident that the general principles are the same. Fairly large trees with full healthy crowns bear the most seed. On account of the great number of medium-sized, immature trees present in most Douglas fir stands, a smaller number of large trees than is required in the ponderosa pine type will usually suffice.

Soil moisture is usually regarded as the all-important physical factor; it probably is dominant, but heat, light, and atmospheric humidity are also important. At the lower limits of the type and on southerly exposures, deficient soil moisture and high evaporation are the critical factors. Near the upper limits of the type and on northerly exposures throughout the upper half of the Douglas fir range, deficient heat is likely to be more limiting than deficient moisture. But even in the high altitudes where the climate is generally cool and moist, sites exposed to high wind or strong sunlight may impose drought conditions by inducing excessive transpiration. Douglas fir is very susceptible to winterkilling; this is true especially in Colorado and northern New Mexico. Unseasonable frost is another factor that may prevent or seriously retard seedling growth on certain sites. Douglas fir is more susceptible than most species to freezes in late spring after growth has begun.

Removal of trees by cutting or other means decreases root competition for the time being and, theoretically, should increase the soil moisture. Undoubtedly, the moisture available to well-rooted seedlings is increased, but opening the crown canopy accelerates evaporation and this decreases the moisture content in the upper inch or two of soil. Drying out of this superficial layer is fatal to germinating seeds and tender seedlings. Exposure to strong insolation also accelerates the rate of transpiration, and thus, though the total available moisture supply may have been augmented, this increase may be offset or overbalanced by increased water consumption. Opening the crown canopy may also stimulate the growth of weeds and brush which, if dense, exact a heavy toll from the moisture supply. It is safe to say that usually cutting increases the moisture supply available to older seedlings; but carried to the extent of exposing large portions of the soil area to wind and direct sun, it tends to create an unfavorable moisture balance for young seedlings.

Light, in the technical sense, is probably seldom a limiting factor in reproduction of Douglas fir, but the heat of direct sunlight may be needed in the cooler situations. Low temperature is the factor which directly limits the upper range of Douglas fir in the Southwest. On sites where the air temperature is below the optimum, the heat made available under direct sunlight may be the deciding factor in favor of

survival. Of the associated species, alpine fir and the spruces have lower heat requirements than Douglas fir, ponderosa pine higher, and white fir very nearly the same. This means that on north exposures above the middle range of Douglas fir, the crown canopy should be opened up as much as is consistent with seed supply and wind protection. Unless this is done, alpine fir (*Abies lasiocarpa* (Hook.) Nutt.), blue spruce, and Engelmann spruce are likely to take possession. White fir is also favored in shaded situations, though perhaps less on account of low heat requirements than low light requirements and ability to become rooted in litter. On relatively warm sites, such as south exposures, large openings favor ponderosa pine or limber pine. On such sites, Douglas fir comes in well under light or moderate cover.

Douglas fir requires a mineral soil for permanent establishment of seedlings, but this should not be interpreted as meaning a bare soil. A bare soil dries out too fast on the surface. An inch or two of well-decayed organic matter on the surface, underlain by mineral soil, provides ideal moisture conditions. In the absence of decayed material, leaf litter, stems, etc., if not too deep, are beneficial. The deep layers of more or less dry, undecayed, or only partially decayed duff usually found under tree groups are unfavorable to seedlings unless this material becomes thoroughly soaked and stays wet throughout the first season. Such a condition is brought about only in years of exceptionally heavy summer rainfall.

What has been said about cutting and seed bed has a direct bearing upon brush disposal. In exposed situations where the stand is too open to give adequate protection to the soil, scattering brush may be of appreciable benefit. On the other hand, on cold, shaded slopes, unburned slash is an obstruction to the much-needed sunlight. On such sites undecayed litter is usually deep and thus slash left on the ground aggravates an already undesirable condition.

In Colorado, Roeser (*16*) has found that the best reproduction of both Douglas fir and Engelmann spruce is obtained under the shelter-wood method of cutting, although nearly as good results were obtained by the selection method. In both of these methods crown cover plays an important part by decreasing wind and evaporation. The cutting is not heavy enough to open up the crown canopy excessively, and yet the removal of some of the trees decreases root competition. The method of brush disposal has not been found to influence reproduction of Douglas fir in a marked degree, one way or the other. The findings in Colorado should apply to northern New Mexico where conditions are quite similar. In southern New Mexico and southern Arizona, however, experiments comparable to those in Colorado have given negative results, indicating that here we are dealing with other factors more potent than method of cutting or brush disposal.

Grazing presents less of a problem in the Douglas fir type than in the ponderosa pine type. This is because use of the Douglas fir forests is confined more strictly to summer grazing. Also, the forage during the few months when stock are held in the Douglas fir type is unusually succulent. Douglas fir and white fir seedlings, however, are even more subject to browsing than are ponderosa pine seedlings, and for this reason the danger of grazing damage should not be overlooked.

Fires are generally infrequent in this type of forest, but once started they are very destructive, usually killing everything. Here again the practice of burning slash commends itself. Old burns in which the

original stand was almost completely destroyed, occupy thousands of acres. Usually these burns have grown up to aspen which acts as a nurse to such coniferous species as are favored by light shade. On extensive areas where seed trees have been left, aspen-covered burns are being restocked by Douglas fir and other conifers; but where no seed trees occur, reproduction is lacking. Because of the density of the stand after cutting, brush burning requires great care in order to avoid killing young trees.

ENGELMANN SPRUCE TYPE

GENERAL FEATURES

This type occurs immediately above the Douglas fir type and extends to the upper limits of tree growth. It is found mostly above 10,000 feet, though extending lower on northerly exposures. Sometimes the stand is practically pure spruce, but more often this species occurs in mixture with corkbark fir (*Abies arizonica* Merr.) or alpine fir. At the lower limit of the type there is also Douglas fir, white fir, and limber pine. Bristlecone pine (*Pinus aristata* Engelm.) occurs sparingly, being confined to openings on the south and west slopes. Spruce stands are denser than those of the Douglas fir type.

Precipitation is not appreciably higher at these altitudes, but the temperature is lower and therefore evaporation is less. Snow persists well into June. The severe drought of May and June which characterizes the low altitudes in Arizona and New Mexico is scarcely perceptible in the spruce forests.

All of the species except bristlecone pine, which grows mostly on open, exposed sites, are able to make good growth in moderate shade. Maximum yields reach 30,000 board feet per acre for small areas in the Graham and San Francisco Mountains. Yields as high as 50,000 feet are reported for the upper Rio Grande Basin of Colorado. On the average they are not over 10,000 feet per acre for large bodies, and sometimes still less. The spruce, like the Douglas fir type, is very patchy because of old burns probably preceded by insect attacks. Large areas have grown up to aspen, but on many of these the conifers are returning. Other areas, usually in high altitudes, remain bare of both aspen and conifers.

IMPORTANCE OF NATURAL REPRODUCTION

The reproduction problems of the Engelmann spruce type are similar to those of the Douglas fir type. To a large extent they are solved by the presence of advance reproduction. Where advance reproduction does not occur at the time of cutting, real difficulties are encountered. Because of the extremely delicate character of Engelmann spruce seedlings in this region, the need for adjustment of temperature and moisture conditions to their requirements is even greater than in the case of Douglas fir. They are extremely sensitive to drying of the surface layers of the soil during and for several months after germination. This is probably the reason why the type tends to avoid south exposures. Although Engelmann spruce and alpine or corkbark fir are distinctly cold-climate trees, there are indications that reproduction is hampered by low temperature on north slopes at altitudes above 10,500 feet. Seedlings start under cover on such slopes, but they do not grow well, and usually die at an

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age of 3 or 4 years. Better growth is made in large openings, but germination is poorer. In practice it is extremely difficult to so regulate cutting as to obtain the proper control of surface soil-moisture and temperature. The problem is further complicated by the fact that spruce stands when disturbed by cutting are subject to windfall.

Deep layers of undecomposed litter are detrimental to both spruce and fir reproduction, but especially to the spruce. These accumulations are greatest on the coldest sites. On such sites the burning of slash is desirable if it can be accomplished without too much damage to the residual stand. Although fires are uncommon in the spruce forest, they are extremely destructive when they do occur.

As previously stated, Roeser (*16*) has found the shelter-wood and selection methods of cutting best for reproduction of both Douglas fir and Engelmann spruce.

SUSCEPTIBILITY TO DAMAGE AND DISEASE

INSECTS

Several species of bark beetles are more or less common, and have demonstrated their ability to kill timber in large quantities. The Black Hills beetle (*Dendroctonus ponderosae* Hopk.) has been the most destructive. In a period of several years around 1900 it killed over half a billion board feet of ponderosa pine in the Black Hills. Between 1920 and 1925 the same beetle was responsible for the loss of 300 million board feet of ponderosa pine on the Kaibab National Forest in northern Arizona. This insect is not known to have assumed epidemic proportions on the Colorado Plateau south of the Colorado River.

Dendroctonus barberi Hopk., associated with *D. approximatus* Dz. and *Ips lecontei* Sw., became sufficiently active on the Prescott National Forest in 1928 and 1929 to call for control operations. All of these beetles are more or less common throughout the Southwest. Although they are generally less aggressive than the Black Hills beetle, they nevertheless account for a considerable timber loss over a period of years. The killing of isolated trees reserved for seed production on certain areas may prove especially serious in its effect upon natural reproduction.

The pine beetles of the genus *Ips* attack mainly young trees in the sapling and pole stages. It has been suggested elsewhere that *Ips* accompanying or following prolonged droughts may account for the excessive thinning, or group killing, of young stands of western yellow pine in the lower fringe of the type. A characteristic of these beetles is that they commonly attack young trees in the vicinity of freshly cut slash.

The spruce budworm (*Cacoecia fumiferana* Clem.) and the hemlock looper (*Ellopia* spp.) are serious pests in spruce and fir forests. The spruce budworm occurs over a wide range. It appears to work more or less intermittently, killing some trees and greatly lowering the vitality of others, but seldom destroying a whole stand. The hemlock looper attacks firs, completely defoliating and killing both old and young trees. Fortunately, this insect has been reported in this region only in the Sacramento Mountains.

Two species of tip moth are prevalent in the Southwest.[6] The most common one, *Rhyacionia neomexicana* (Dyar), deposits its eggs on young pine shoots and the larvae bore in and up the shoot, devouring the tender inside tissues and causing the shoot to die above the point of attack. On extensive areas near the lower border of the pine zone nearly every seedling is injured, greatly decreasing height growth and in extreme cases causing death. From the middle altitudinal portion of the zone upward the amount of damage decreases. The damage also decreases as the young trees grow up beyond the sapling stage. A less common form of injury is by the larvae of *Recurvaria condignella* (Busek) which bore a fine tunnel through the pith.

Certain grubs are known to play havoc with seedlings, particularly in plantations, by devouring the roots. Still other insects cut the roots of very young seedlings, causing them to die in the fall of the first season. Much of the infant tree mortality formerly attributed to drought is thought to be the result of insect activity.

Larvae which feed on the immature seeds of ponderosa pine take a tremendous toll from the seed yield of this species. In some localities this is a very important factor in the failure of natural reproduction.

RODENTS

The most common rodents of the forest are seed eaters, and for this reason they are usually regarded as forest enemies. In this class are mice, chipmunks, and mantled ground squirrels. Although these animals aid to some extent in disseminating and planting seeds and may at times eat insects, their activities are thought to be mainly harmful. Field mice, in addition to eating seeds, may do enormous damage by girdling pine seedlings. Pack rats have been known to cut off or girdle seedlings, but they also cut down competing vegetation. To what extent they eat conifer seeds is not known. Pocket gophers gnaw the roots of conifers along with those of other plants. Their depredations in this respect are probably more than offset by their burrowing in the soil, which, though objectionable in cultivated fields and around stock tanks, is beneficial to forest soils. The mantled ground squirrel also burrows in the ground, which may in part at least balance his seed account. The Bureau of Biological Survey has developed successful methods of poisoning all of the above rodents. It is probable that natural forest reproduction could be materially aided by controlling mice, chipmunks, and mantled ground squirrels. In two series of experimental plots uniformly seeded to ponderosa pine in 1929, the plots screened against rodents contained 1,781 seedlings on August 22, as against 618 seedlings on an equal area of unscreened plots. In a series of Douglas fir plots seeded in 1932, screened plots at the close of the first season contained an average of 81 seedlings per plot as against 2 on unscreened plots.

Tree squirrels are also active seed-eaters, but are placed in a different class because of their esthetic and economic value. Both the Abert squirrel and the spruce squirrel are protected by the Arizona and New Mexico game laws, subject to an open season. The Abert squirrel, in addition to consuming great quantities of pine seed, cuts off the young shoots of pine trees. He has the habit of attacking the

[6] Determinations by the U. S. Bureau of Entomology and Plant Quarantine.

same tree year after year, with the result that the crowns of such trees become greatly thinned and the general vigor reduced. The cutting of shoots in winter often destroys great quantities of first-year cones. The consumption of second-year cones begins in August and continues until the seeds are shed. In years of light or moderate cone yield, it is not uncommon to see practically the entire crop on large areas consumed by the Abert squirrel before the seeds mature. The Abert squirrel should not be exterminated, but his numbers should be limited.

Perhaps the most harmful of all rodents in the forest is the porcupine. He begins eating the bark of pine seedlings when they are 6 inches high and continues throughout the life of the tree. Seedlings and saplings are killed by girdling near the ground; poles and immature trees are deformed by girdling of the main stem near the top. On mature ponderosa pine the damage is confined mainly to the branches and tops, but mature spruce trees are barked any place on the main trunk. On areas where seedlings start sparingly, a single porcupine working year after year can prevent restocking on many acres. On spruce and fir burns and on clean-cut pine areas, occasional saplings which would eventually become seed trees are often killed by the porcupine. Although his work is deadliest on thinly stocked areas, he can practically ruin fully stocked stands of poles or saplings. Extensive investigations of the life history of the porcupine by Taylor [7] have disclosed no useful habits in the porcupine, except that he eats mistletoe, and this is a doubtful asset. Eating the stems of mistletoe does not kill it; on the other hand, it is reasonable to suppose that the porcupine aids in the dissemination of mistletoe by carrying the seeds and by wounding the bark of trees.

PREDATORY ANIMALS AND BIG GAME

From time immemorial, man has regarded wolves, coyotes, mountain lions, bobcats, and other animals which prey upon livestock as traditional enemies, to be killed on sight. Although no figures are available to prove the assertion, it is almost certain that this warfare has resulted in a large increase of the rodent population. It is reasonable to conclude that the killing of carnivora which normally live on mice, chipmunks, squirrels, and porcupines, not to say large browsing animals, is detrimental to the forest. Where the control of predatory animals is deemed necessary in the interest of the livestock industry, it should be accompanied by equally intensive control of the enemies of the forest.

BIG GAME

Some years ago the suggestion that deer might become so abundant as to cause damage to forests was received by the public with skepticism if not amusement. Yet, at that time, excessive browsing by deer was coming into evidence in the Grand Canyon Game Preserve. In 1930 the situation had become so acute that forest officers urged the removal of large numbers of deer (fig. 13.) Similar though less critical conditions have developed in the Santa Catalina Mountains and Mount Graham of southern Arizona, and on the Cibola and Gila National Forests of New Mexico. In some of these areas, deer are

[7] The results of these investigations by Walter P. Taylor, of the Bureau of Biological Survey, have not yet been published.

damaging shrubs and young forest trees to such an extent as to endanger the forest and destroy the forage upon which the deer themselves are dependent. Overstocking by deer is far worse than overstocking by cattle and sheep because deer cannot be removed except as small numbers are killed or captured.

DISEASE

Thus far the greater portion of the research work on tree diseases in this region has concerned the decay of wood. The loss of merchantable timber through decay in the woods is enormous. The cull scale of ponderosa pine in logging operations generally runs between 10 and 15 percent of the total cut. This, however, represents but a small portion of the total loss during a rotation because it does not take into account the large number of trees that have died wholly or

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FIGURE 13.—Juniper defoliated by deer as high as the animals can reach; cliffrose in foreground completely defoliated or killed. Grand Canyon Game Preserve, 1930.

partly as a result of decay or which have rotted after being killed by other agencies.

The high percentage of cull due to rot may be attributed in part to the general overmaturity of the forests being logged at the present time. In future generations, few trees will be allowed to attain an age of more than 200 years, and this should automatically decrease the percentage of heart rot. On the other hand, second-growth stands, because of their more limby character, will be more subject to attack by rotting fungi. The heart rots gain entrance mainly through dead limbs which have attained sufficient size to contain heartwood. A practical remedy and perhaps the only one that can be generally applied is to grow young forests in dense stands. If the trees from the sapling stage up through the pole stage are spaced closely enough so that the lower limbs will die before appreciable heartwood has developed, the limbs will not only drop off more quickly and thus permit the formation of clear lumber, but they will not provide a point of entry for heart rots.

A large part of the high mortality in young seedlings is not directly traceable to drought or mechanical injury, and it is reasonable to suppose that pathological agencies play an important part. The common nursery disease, "damping off", is relatively inactive under forest conditions. An ailment known as "blight" is attributed to superheating at the ground line and may be alleviated by providing light soil cover in the form of needle litter, dead branches, and herbaceous vegetation. It seems probable that a thorough study of seedlings would reveal a large number of diseases which are not now recognized.

MISTLETOE

Of the organisms attacking living trees, ponderosa pine mistletoe has received most attention in forest management (*6*). Investigations have shown that mistletoe retards the growth of trees perceptibly and that many trees are killed by it. Records by the Southwestern Forest and Range Experiment Station over a period of years indicate that immature trees are more susceptible to attack and are more likely to be severely injured than are mature trees. Young trees bearing an appreciable amount of mistletoe are almost sure to succumb sooner or later. Regardless of whether a mistletoe-infected tree survives, it is a menace to surrounding trees and especially to those in the sapling and pole stages.

MINIMUM MEASURES NECESSARY TO KEEP FOREST LANDS PRODUCTIVE

Where the growth of trees is as slow as in the Southwest, timber growing as a commercial enterprise cannot as a rule be expected to appeal to private capital. But most forest lands will yield even lower returns under other forms of use.[8] The best outlet for the private owner of cut-over lands should be eventually to sell them to some public agency which, because of important indirect values such as regulation of stream flow or recreation, in addition to timber and forage crops, can afford to own and manage forest lands under conditions that would be unprofitable to the individual. But it is poor economics for the State or Federal Government to purchase cut-over lands for timber growing after they have been abused to such extent that they will not respond to management without large expenditures for reforestation. Lands which bear a fair stand of seedlings and saplings or enough seed trees to insure natural restocking in 30 or 40 years have potential forest value; but lacking both reproduction and seed trees they are a doubtful asset because the cost of planting under most conditions is prohibitive.

Devastated lands are not only unproductive but they may become a public menace. Clear cutting followed by fire and overgrazing may cause floods and erosion and result in untold damage to storage reservoirs, highways, and other property (fig. 14). Also, the land itself deteriorates through removal of the fertile topsoil, so that its productive capacity for both forest and forage crops is greatly impaired. No country can long afford to allow its soil and water

[8] It has been estimated that on the basis of current prices received for stumpage and grazing permits by the Forest Service, the annual per acre growth of ponderosa pine under management and accessible to markets is worth from 5 to 10 times as much as the annual forage growth would be if the same land were clear cut and devoted entirely to grazing. In comparing gross value of products, employment, and other social values, a similar relation exists. The highest returns are obtainable by a judicious combination of timber growing and grazing.

resources to be wasted. Forest destruction is more than a timber problem; it is also a land and water problem which the Nation, the State, and the community must face sooner or later.

As stated in the introduction, the measures prescribed as necessary to keep forest lands productive represent a standard of forest practice that aims but little higher than merely avoiding forest destruction. This brand of forestry, if it may be called such, cannot be expected to produce profitable timber crops except under the most fortunate circumstances. Good stands of timber will grow up on some areas; on others the margin above devastation will be narrow. If these measures succeed in preserving the soil cover and a sufficient number of trees to insure fair natural restocking in the course of 30 or 40 years after cutting, their main object will have been attained. No standards are set as to yields or time of a second cut.

Growing a timber crop involves two major activities—stocking the land and protecting the growing stand. For economic reasons

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FIGURE 14.—Soil erosion following heavy cutting, fire, and overgrazing. In addition to the gullies, the topsoil is being removed by sheet erosion.

the land must be stocked mainly by natural means. In regions where adequate reproduction is assured, stocking requires little or no attention unless, as in the Black Hills, young stands tend to become overdense and require thinning. Protection is primarily an aid to reproduction, but it must be continued after stocking is complete. The degree to which a given forest area approaches its full productive capacity depends almost entirely upon the success attained in stocking the land and in protecting the growing crop until it reaches maturity. If the land is only one-half or one-third stocked, or if restocking is unduly delayed, the annual yield will be decreased in corresponding measure. If 10 percent of the land is overrun by fire after cutting, the forest capital on this portion of the area becomes virtually a total loss for 50 years or more. Young pine stands up to 60 years old and fir and spruce of greater age are subject to complete annihilation by fire. Other inimical factors against which protection must be provided are improper grazing, disease, insects, and rodents.

The specific precautions necessary to assure keeping forest lands productive vary somewhat with the species, as well as with climate and industrial practices. Because of its wide-spread occurrence and great economic importance, the ponderosa pine type will occupy the foreground in the presentation which follows, and the measures here prescribed are designed primarily for ponderosa pine. Nevertheless, the other forest types, such as the Douglas fir and the Engelmann spruce, have enough in common with ponderosa pine to permit their being discussed concurrently, and where distinctly different treatment is called for, specific measures will be given. All the measures presented are naturally associated with major forest activities and involve special provision in regard to fire, cutting and removal of timber, disposal of logging debris, and grazing.

FIRE PROTECTION

Measures which will prevent burning of cut-over lands to a substantial degree and which will restrict fires to a minimum in virgin stands are of paramount importance. Protective measures naturally fall into two general classes: (1) Those that have to do with organization—personnel, improvements, equipment, planning, etc.; and (2) methods of slash disposal. In view of the fact that slash disposal has some silvicultural bearing, discussion is simplified by separate presentation.

An effective organization must be able to detect fires quickly, reach them promptly, and extinguish them while they are small. A good example of such an organization is that of the Forest Service in the Southwest. This organization consists first of primary lookouts, stationed on peaks overlooking a large expanse of country, who are continuously on the watch for smokes, and firemen located at convenient points in readiness to proceed to a fire at a moment's notice. The headquarters of all permanent officers are connected by telephone. On sighting a smoke the lookout determines its direction by means of an alidade and protractor, and transmits this information by telephone to some central point, usually the supervisor's office. Corresponding readings are received from other lookout points. Then by intersection or triangulation on a map at the central point the fire is located definitely and the nearest fireman is sent to it. In case of large fires or great fire hazard temporary labor is obtained from nearby ranches, towns, logging camps, etc. All forest users, particularly, are depended on for aid in fire suppression.

It is difficult to outline measures with costs that will fit individual cases accurately, since these vary not only with the region but also with circumstances of individual cases. There is one intangible element without which no mechanical requirements will ever be entirely successful, and that is a desire and determination on the part of operators and lessors of forest properties, and their employees, to prevent and suppress fires.

With this explanation the following is offered as the best statement that can be made as to measures necessary under average conditions, localized, where it seems worth while, by regions:

(1) Protective machinery consisting of a permanent organization supplemented by lookouts and firemen, telephone communication, roads and trails, fire-fighting equipment, and cooperation with Government and private agencies, that will represent a manpower

in every part of the region, except the southern Rocky Mountains, equal to 1 man to every 40,000 acres of virgin timber or 20,000 acres of cut-over land—this to be maintained during a season running from May 1 to July 10 on the Colorado Plateau, April 15 to July 15 in the border region, and May 1 to October 31 in the Black Hills. In the southern Rockies 1 man to 90,000 acres virgin or 50,000 acres cut-over is sufficient, for a season from May 15 to July 15.[9]

(2) The use of oil for fuel, wherever practical to secure it, in all steam-logging machinery.

(3) Efficient spark arresters on all locomotives and other steam-logging machinery and sawmill engines where so located that sparks therefrom might start forest fires.

(4) The equipment of logging locomotives, steam loaders and skidders, logging camps, and sawmills in the vicinity of forest lands with suitable fire-suppression tools.

(5) For each logging operation a written plan of action for the prevention and suppression of forest fires, which will outline the organization of camp or woods personnel, individual responsibilities, etc.

(6) During periods of abnormally high fire hazard, prohibition of smoking on cutting areas; in cases of extreme hazard due to climatic conditions, suspension of operation where this can be shown to be advantageous.

(7) On the Colorado Plateau the prompt felling of dead snags on all cutting areas except spruce; in other regions snags need be felled only on fire lines and areas of special hazard.

(8) Removal of slash and debris on areas of special hazard, usually by piling and burning, in advance of the regular fire season or other periods of fire danger. These areas of special hazard include logging railroad rights-of-way, the vicinity of steam-logging machinery, sawmills, camps, highways, etc.

Paragraph (1) is intended to approximate the intensity and method of organization maintained by the Forest Service. The presence on national forests of year-round administrative officers who augment the purely protective organization renders it difficult to give figures of cost, area per man, etc., comparable with what would be needed by the large private owner organized for protection alone. It should be appreciated also that this organization scheme contemplates large holdings of forest land, and in a region of many small holdings would be adequate only with the utmost degree of cooperation between individual owners.

The average cost of fire prevention, including improvements, on the national forests of Arizona, New Mexico, and Colorado, as shown by the records of the Forest Service, is 1 cent per acre per year, of which half is for improvements.

An organization such as is outlined in the preceding pages will extinguish the majority of forest fires while small and will avoid the expense of additional labor. In spite of all precautions, however, occasional large, expensive fires do occur. For the national forests of Arizona and New Mexico the average annual per-acre cost of suppression, made up largely of the costs of these large fires, is about 3 mills, when prorated against the total forest area. In Colorado

[9] The seasons here given apply particularly to the ponderosa pine type. They usually begin about 2 weeks later in the Douglas fir type and a month later in the Engelmann spruce type.

this figure is placed at 5 mills. The combined cost of prevention and suppression in the Southwest therefore varies from 1.3 to 1.5 cents per acre annually.

In the Black Hills the combined cost of prevention and suppression, including improvements, averages 2.3 cents per acre annually.

The manner in which cut-over areas are intermingled with virgin areas and are covered by common lookouts complicates the differentiation of cost of fire prevention between the two classes of land. For similar reasons the sharp differentiation in area per man between virgin and cut-over areas indicated in item (1) cannot always be attained in practice. The point is, however, that a more intensive organization must be assured for cut-over areas, even though they intermingle with virgin timber. Because of the increased growth of grass, weeds, and saplings after cutting, the special hazard is not removed entirely with the disposal or rotting of the slash, and therefore an intensive organization must be continued for 20 or 30 years, at least.

Items (2) to (8) are obviously in the nature of special precautions in connection with lumbering operations and cut-over lands. Except for dead-snag felling, which on the Colorado Plateau costs about 30 cents an acre, it is impossible to make an accurate estimate of the cost of these items on a volume or acreage basis. As a matter of fact, they are offset very largely, if not entirely, by corresponding decreases in the costs to operators of fire suppression, loss of equipment, logs, etc. All too frequently in past years individual forest fires have cost lumbermen hundreds if not thousands of dollars. In more recent years, due mainly to the above measures, fire losses on the national forests have been very light.

SLASH DISPOSAL

As previously stated, the principal purpose of slash disposal is to facilitate the control of fires. With fire control as the primary object the following measures are necessary. Such further practices in connection with slash as are principally for the silvicultural welfare of the forest will be covered under Measures Necessary to Produce Full Timber Crops.

BLACK HILLS

Pile and burn all slash, except on steep slopes and in open stands on south and west exposures, where it should be lopped and scattered.

SOUTHWEST

Pile and burn all slash on fire lines 100 to 200 feet wide and so located as to break up the cut-over area into blocks of not more than 160 acres. Also, pile and burn slash on areas of special fire hazard as defined under Fire Protection, item (8).

It is not the function of this bulletin to give a detailed treatise on piling and burning slash. At the same time, without setting hard and fast rules as to details, it may be helpful to record as guides certain general principles drawn from Forest Service experience (fig. 15).

One of the essentials is prompt piling. Slash handles more easily and can be piled better and more cheaply while green. When dry, the needles shake off and the protective measure thereby loses much of its effect. Moreover, if promptly piled the slash settles into a compact mass and is ready to burn at the first favorable opportunity. The Forest Service aims to have slash piled within 6 weeks after

cutting unless prevented by deep snow. Promptness is especially essential on fire lines and areas of extraordinary hazard.

It is not practical to pile and burn the large pieces. The usual practice is to trim up and throw aside stems more than 4 inches in diameter.

Piles should be made as compact and as nearly tepee-shaped as possible. Large piles, from 6 to 8 feet in diameter and from 4 to 6

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FIGURE 15.—*A*, Brush piled for burning on a national-forest cutting area. *B*, Brush piles burned with little damage to seedlings. The coarse limbs on the ground are not very inflammable, and they tend to favor the establishment of additional seedlings.

feet in height, burn best. Piles should be located as far as practical, and usually not less than 20 feet, from living trees and clumps of saplings, or else size of piles should be kept down sufficiently to prevent damage to the remaining stand.

Burning can be done most effectively and safely with snow on the ground. The next choice is during rainy periods. Where it is

urgent to clear promptly areas of special hazard, night burning may be practiced if conditions are not favorable in the daytime. A special effort should be made to avoid letting dry slash lie through the dry early summer. Piles so located as to threaten excessive damage should be left unburned. The special precautions that are needed to keep fires within control may require patrol for a week or more after burning to prevent spread of fire from smoldering logs or litter.

A method of slash disposal which from limited experiments appears promising and which might under some conditions be substituted for piling and burning is what may be termed "green" or "swamper" burning. The slash as it is cut from the trees is thrown directly upon stationary fires. This method, of course, is usable only when the ground is snow-covered or quite wet. At such times the results are a cleaner disposal and less damage than under the usual method of piling and burning.

In the Black Hills effective slash disposal is an indispensable means of fire control and is believed to be the crucial item in keeping forest land productive. The Homestake Mining Co., which is the largest owner and operator of private timber in the Black Hills, practices piling and burning uniformly. It is required on Forest Service timber sales and on State sales. In the Southwest there is no slash disposal on private lands.

It is estimated that the requirements will cost [10] as follows:

PONDEROSA PINE TYPE

Black Hills (complete piling and burning), 50 cents per thousand board feet cut, or $2.50 per acre; Colorado Plateau (piling and burning on fire lines), 15 cents per thousand board feet cut or $1.05 per acre; southern Rockies (clearing fire lines), 15 cents per thousand board feet cut, or 75 cents per acre.

DOUGLAS FIR AND ENGELMANN SPRUCE TYPES

Since for these types piling and burning on fire lines is uniform for all regions, differences in cost will be determined largely by the amount of debris to be handled. The figure of 15 cents per thousand board feet of total cut furnishes a fair basis for calculation. The cut per acre will vary from 5,000 board feet in the southern Rockies to 20,000 board feet in the Sacramento Mountains, and the corresponding costs will vary from 75 cents to as high as $3 per acre.

CUTTING [11]

The primary purpose in regulating cutting as a minimum requirement is to preserve seed trees where these are needed and so avoid excessive denudation (fig. 16). Where complete advance reproduction exists and can be preserved through the logging operation, seed

[10] The various items of cost given in this bulletin are based on wage scales and other price trends prevailing before 1930.

[11] As this bulletin goes to press, a modified set of minimum requirements is being put into effect under the provisions of schedule C of the lumber code. The main difference between the two sets of requirements is that those here outlined specify that seed trees must be of good form, while the rules prescribed under schedule C permit them to be of low value for lumber, provided the crowns are thrifty. In drafting of code requirements under schedule C it was necessary to take into account the fact that the code deals with timber operators as distinguished from landowners. Since few of the operators in the Southwest own the land on which they are cutting, and most of those operating on private land are under contracts which call for removal of all merchantable timber, it seemed unjust to demand that they sacrifice the values represented by seed trees of high merchantable quality. Obviously the direct cost of minimum requirements should be borne by the landowner who will reap the benefits.

trees are obviously unnecessary. Such is usually the case in the Black Hills. In the Southwest, seed trees are generally needed, although in some sections the presence of fairly complete advance reproduction makes it possible to reduce the number or the size of the seed trees left. As already pointed out, trees below a certain size, varying somewhat with the species and the region, cannot be relied upon to produce enough seed for natural reproduction on a large scale. The seed trees, if of the right type, will contribute substantially to the next cut, and for this reason it is important to select good, thrifty trees. Such trees will as a rule pay their way by increased growth in addition to seed production, whereas poor trees are likely to be a total loss. The major item in the second cut will be the young trees just below merchantable size at the time the first

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FIGURE 16.—Ponderosa pine area 40 years after logging. The trees left were too few and too small to provide adequate seed for reproduction; some are now of seed-bearing size and a few seedlings are starting. At least 100 more years must elapse before a second cut can be made.

cut is made. The number of these will depend on the character of the original stand, and also upon the type of cutting. If the operation removes only saw timber, more of the fairly large-sized immature trees will be left than if ties, stulls, and props are taken. This affects not only the residual stand but also seed production, because, although individual small trees bear only a small quantity of seed, a large number, if well distributed, may become an important factor in reproduction:

The minimum requirements for different forest types, regions, and conditions, and the estimated costs, including stumpage and increased depreciation and spur charges, are as follows.

PONDEROSA PINE TYPE

BLACK HILLS

(1) Advance reproduction of at least 500 established [12] and well-distributed seedlings, saplings, and poles [13] per acre present: No restrictions.

[12] Seedlings are not considered established until they are about 1 foot high.
[13] The term "poles" is used to designate young trees 4 to 12 inches d. b. h.

(2) Advance reproduction below the above specifications: Leave 4 seed trees per acre more than 14 inches d. b. h. (volume about 500 feet board measure per acre).

In the Black Hills it is estimated that at least 90 percent of the area will fall under condition 1. Reproduction is easy to get and is nearly always abundant in uncut stands. In fact, reproduction is often considered too dense for good development.

SOUTHWEST

(3) Advance reproduction of at least 200 established and well-distributed seedlings, saplings, and poles per acre present:

(*a*) Leave all thrifty trees below 16 inches d. b. h. (volume about 165 feet b. m. per acre); or

(*b*) Leave 2 seed trees per acre over 17 inches d. b. h. (volume about 500 feet b. m. per acre).

(4) Advance reproduction as above described not present:

(*a*) Leave all thrifty trees below 21 inches d. b. h. (volume about 550 feet b. m. per acre); or

(*b*) Leave 3 seed trees per acre over 17 inches d. b. h. (volume about 900 feet b. m. per acre).

In the Southwest, condition 3 will apply to most of the ponderosa pine type, but important exceptions may be found where grazing and fire have not been adequately controlled. The alternatives provided are designed to permit either an exclusively saw-log operation by cutting to a diameter limit, or the cutting of ties, stulls, and props and restocking by seed trees. According to Coconino National Forest stand tables, cutting to a 15-inch diameter limit would leave 12.3 trees per acre from 6 to 11 inches d. b. h., and 2.8 trees 12 to 15 inches d. b. h., or a total volume of 165 feet board measure. Tie, stull, and prop cutting removes practically everything down to 7 inches. The 2 seed trees required under this alternative would in practice range from 18 to 22 inches, inclusive.

Corresponding alternatives are provided in condition 4. The essential difference is that there is less advance reproduction and therefore better provision for seed is required. The Coconino stand tables indicate that when the cutting is to a 20-inch diameter limit there will be left about 12 trees 6 to 11 inches d. b. h. and 5 trees 12 to 20 inches, the latter class having a total volume of about 550 board feet. When 3 seed trees over 17 inches are to be left, the actual diameters will range from 18 to 25 inches and the total volume will be about 900 board feet. The first alternative will obviously be preferred by the saw-timber operator on account of the smaller volume left, especially in the larger diameters. At the same time, the land remains in fairly good condition because the deficiency in large seed trees is in a measure offset by the larger number of trees between 6 and 18 inches d. b. h., many of which will attain effective seed-bearing size within 20 years.

A comparison of cutting requirements under different conditions at once reveals the great advantage to the operator of having his lands well stocked in advance of cutting. Since the requirements under (3*a*) and (3*b*) for the Southwest presuppose a rather low average standard of advance reproduction, it follows that on areas of good advance reproduction the requirements might be lowered appreciably, thus reducing the investment in seed-tree stumpage to a low figure.

Private owners who wish to leave their lands in productive condition might well consider postponing cutting until present protection measures have resulted in the establishment of advance reproduction. The difficulty is that it will take from 10 to 20 years to get advance reproduction, and the private owner may not be able to defer so long the conversion of salable stumpage into cash.

DOUGLAS FIR TYPE

Douglas fir stands differ from the typical stands of ponderosa pine in that they are denser, usually having larger numbers of poles and immature trees. For this reason, fewer large seed trees are required. Where the less valuable white fir occurs in mixture, there is a tendency to leave seed trees of this species rather than of Douglas fir. This practice tends to encourage white fir reproduction at the expense of Douglas fir, and although the cutting restrictions do not prohibit this, the owner should be aware of the consequences. The requirements under different conditions of advance reproduction and for removal of different kinds of material are as follows:

(1) Where there is advance growth of more than 500 established and well-distributed seedlings, saplings, and poles per acre, everything above (not including) 12 inches d. b. h. may be cut. This would leave some 40 trees per acre above 4 inches d. b. h. and about 8 trees per acre above 10 inches d. b. h., containing about 200 board feet.

(2) Where advance growth as above described is absent or deficient, two alternatives are provided:

(*a*) All trees above (not including) 16 inches d. b. h. may be cut. This will leave from 15 to 20 trees per acre over 10 inches d. b. h. with a volume of about 800 board feet; or

(*b*) Two seed trees over 17 inches d. b. h. per acre should be left and all other trees above (not including) 12 inches may be cut. The volume of seed trees and others above 10 inches d. b. h. will be about 800 feet board measure.

Condition 2 is more frequently found within the border region, particularly the Sacramento Mountains, than elsewhere. Consequently the retention of seed trees will be particularly necessary there.

Even with seed trees, a minimum diameter limit of 12 inches, which will interfere somewhat with the cutting of hewn ties, is prescribed to prevent, by excessive cutting of small material, the complete removal of the forest cover, which must be avoided in a type which occurs on steep slopes and is important for watershed protection. An ample supply of mine props and stulls may be obtained from tops in this and in other forest types. It should be added that if the owner is in a position to execute thinnings by judicious removal of stems below the diameters indicated, this is very much to be desired. Such removal, however, should be done only under the direction of a forester.

As in the case of ponderosa pine, the cost of leaving seed trees involves both the stumpage value of the trees and the resultant increased depreciation and logging spur charge, but this is similarly offset to some extent by the return from these trees when they are harvested in a second cutting.

ENGELMANN SPRUCE TYPE

The almost universal presence of young growth in the merchantable stands of this type and the habit which both Engelmann spruce and corkbark fir have of producing seed while still small, preclude the need for retaining merchantable trees for seeding. Seed trees would be very difficult to maintain because of the susceptibility of these species to windthrow. It is, however, quite important to maintain a forest cover on the steep slopes characteristic of this type. After seedlings are a foot high they do well in full sunlight.

A diameter-limit method of cutting best fits the case and may be stated as follows: Retain all trees up to and including 12 inches d. b. h. The volume left under this limitation will be almost negligible.

This method is much less conservative than current Forest Service practice, which has as its object the growing of the maximum volume of timber. As stated of Douglas fir, properly directed thinnings, whereby surplus trees of small sizes are removed, are desirable.

LOGGING

The primary purpose of logging restrictions is to prevent unnecessary damage to advance reproduction, seed trees, and young trees normally left because they are of unmerchantable size. Carelessness in the use of steam skidders and tractors and in the felling of trees may destroy a large proportion of the immature growth which, if preserved, makes a creditable contribution to the future forest and in many places is sufficient for a cut in about 75 years. It is recognized that some damage of this sort cannot be avoided, but on the other hand most of the damage in unregulated logging is due to lack of care and foresight on the part of the operator.

No specific limitations are necessary except for steam skidders and tractors. Fortunately, the donkey engine has not been introduced in pine logging in the region nor is there likelihood that it will be. The steam skidder in use is the two-line ground type which reaches out to a maximum distance of 2,200 feet from the track. Steam skidding in pine forests is practical only on the Colorado Plateau and has been used thereon to a limited extent. For this type of skidder, the following measures should be observed:

(1) Ground lines only may be used. These shall be run at right angles to the track.

(2) The skidding trails shall be parallel to each other and must not converge as they approach the skidder. The distance between the skidder trails may vary inversely with the volume of timber cut per acre.

(3) Logs may be skidded into the trails by horses, not by side-haul lines.

(4) Every reasonable care must be taken to prevent unnecessary damage to reproduction.

These measures, conforming with Forest Service practice, have been found after several years' experience by large operators to be practicable. So restricted, steam skidding is not a bad thing silviculturally. Skidder trails, where the soil is stirred up and grass removed, favor reproduction and also make fair fire lines. On steep slopes, slash should be thrown into the trails to prevent erosion.

Portable and semiportable overhead Lidgerwood skidders have been used in Douglas fir logging in the Sacramento Mountains. While under the best practice Lidgerwoods may be ruled out, it is not believed justifiable to do so unless the aim is to practice better forestry than is required merely to keep the lands productive. The necessary precautions may be stated as follows:

(1) In using steam skidders, irrespective of type, the skidder trails must be at least 500 feet apart at their outer extremities.

(2) Logs must be pulled into the skidder trails, either by horses or by machinery, at right angles to the trail.

An additional word should be said about tractor logging, which has come into general use during recent years and promises to become the prevailing method. In the hands of a thoughtless driver, the tractor is capable of great destruction. Crashing through thickets of saplings or small poles can be avoided to a great extent by laying out routes of travel in advance. Swinging logs sidewise through groups of young growth, and skidding logs from which the limbs have not all been removed should be prohibited.

It is not believed that the above measures will generally entail appreciable added expense over an unrestricted system in this region.

GRAZING

Control of grazing is necessary not only to protect forest reproduction, but also to insure maximum returns from the forage crop. Investigations by Hill (*5*), Cooperrider,[14] and others in the Southwest point to overgrazing [15] rather than grazing per se as the main cause of damage to forest reproduction by livestock. That reduction of stocking is effective has been demonstrated on a large scale on the Coconino, Kaibab, and Sitgreaves. Destructive grazing damage that had continued over a long period of years was checked on extensive areas by heavy reductions of cattle and sheep in and about 1926. On many allotments the reductions expressed in animal-months were as high as 50 percent or even more. The decrease in numbers was accompanied by a shortening of the grazing season, and by fencing and other measures which resulted in better distribution of stock. Although damage still persists in some localities, conditions in the region as a whole have been greatly improved. It cannot be said that range management such as required in the interest of livestock production alone will insure adequate protection to forest reproduction; but the results will in most instances compare favorably with other protective standards in the type of forestry contemplated under Minimum Measures Necessary to Keep Forest Lands Productive. The most essential precautions may be briefly stated as follows:

The range should be stocked conservatively (with cattle or sheep, but not both on the same area), adjusting the number of animals to the forage produced in poor rather than good years. If pine seedlings are being browsed over extensive areas, the number of animals or the length of the grazing season should be substantially decreased. Localized damage is usually caused by poor distribution of stock. Concentration of cattle can be lessened by providing adequate water

[14] The results of these investigations by C. K. Cooperrider are not yet published.

[15] Overgrazing, as the term is used in this bulletin, is defined as that use by grazing animals which impairs the sustained productivity of the range. It involves overstocking, incorrect seasonal use, improper class of stock, and local concentration of stock.

and salt at suitable intervals. Sheep should not be bedded on the same ground more than one night in any year. Trailing repeatedly over the same ground should be avoided. The dates for opening and closing the range should be determined by the condition of the forage, and therefore will vary somewhat with localities and years from the average dates of June 1 and October 1; in some instances the opening date could well be deferred until the summer rains are in progress.

SUMMARY OF COSTS

Table 5 summarizes the costs of the prescribed measures in the ponderosa pine and Douglas fir types, insofar as it is practical to estimate them. As in other instances, price levels prior to 1930 have been used. To these figures should be added the annual cost of about 1 cent per acre for fire prevention and 3 mills per acre for fire suppression. In the Engelmann spruce type the only expense, except the above items for fire prevention and suppression, is for brush disposal on fire lines, which will amount to about 15 cents per thousand board feet of total cut.

TABLE 5.—*Cost per acre of minimum logging requirements*

Subregion and cutting requirement [1]	Cutting [2]	Slash disposal	Total
PONDEROSA PINE TYPE			
Black Hills:			
Requirement (1)		$2.50	$2.50
Requirement (2)	$2.35	2.50	4.85
Colorado Plateau:			
Requirement (3*a*)	.68	1.05	[3] 2.03
Requirement (3*b*)	2.12	1.05	[3] 3.47
Requirement (4*a*)	2.35	1.05	[3] 3.70
Requirement (4*b*)	3.40	1.05	[3] 4.75
Border and southern Rockies:			
Requirement (3*a*)	.71	.25	.96
Requirement (3*b*)	2.22	.25	2.47
Requirement (4*a*)	2.46	.25	2.71
Requirement (4*b*)	4.03	.25	4.28
DOUGLAS FIR TYPE			
Colorado Plateau:			
Requirement (1)	.75	1.05	1.80
Requirement (2*a*)	2.90	1.05	3.95
Requirement (2*b*)	2.90	1.05	3.95
Southern Rockies:			
Requirement (1)	.70	.75	1.45
Requirement (2*a*)	2.80	.75	3.55
Requirement (2*b*)	2.80	.75	3.55
Border:			
Requirement (1)	.65	2.70	3.35
Requirement (2*a*)	2.60	2.70	5.30
Requirement (2*b*)	2.60	2.70	5.30

[1] See pp. 42–46.

[2] Includes value of stumpage at $3 per M feet b. m. for ponderosa pine and $2 per M for Douglas fir; also increased rate of depreciation and spur charges due to a reduced cut per acre, estimated at $1.25 to $1.70 per M feet for the pine type and $1.50 to $1.70 for the fir type.

[3] Includes 30 cents to cover snag-felling.

RETURNS

The yields to be expected under the measures which have been prescribed will depend greatly upon the condition in which the forest is left by the first cutting and upon the success attained in protective measures. It should be remembered that in a scheme of minimum requirements the primary purpose is to avoid forest destruction and

that the time that must elapse before a second crop can be cut is a secondary consideration and more or less speculative. Trees between 8 and 20 inches in diameter increase after cutting at a rate of 1 to 1.5 inches in 10 years. Whether or not a logging operation is commercially feasible, however, depends upon the numbers as well as the size of merchantable trees per acre. Usually only a few trees larger than 14 inches d. b. h. will be left, and therefore sufficient time must elapse for adequate numbers of poles to grow to merchantable size.

Where considerable numbers of poles remain after cutting, a second crop may be removed in from 40 to 100 years, depending on the species, the site, the amount of material remaining in the higher diameters, and the size of product desired. Under average conditions ties may be cut in 40 years and saw timber in 60 to 100 years. In the Black Hills and on the best sites of Douglas fir and ponderosa pine in the Southwest, the above periods may be decreased somewhat. Diameter growth is generally slow in the Engelmann spruce type, except when adequately thinned, because of the habit of the species in this type of growing in extremely dense thickets.

If the first cutting leaves fair advance reproduction in the form of seedlings and saplings, but few poles, the second cut will recede in the Southwest to about 80 years for ties and 150 years for saw timber, with possibilities of shortening these periods by 10 to 20 years in the Black Hills and on the better Douglas fir and ponderosa pine sites of the Southwest.

Returns from areas lacking advance reproduction and pole growth at the time of cutting are difficult to estimate because of the uncertainty of restocking. Allowing 40 years for this process and 150 years for growth from seedling to merchantable size, the total period becomes 190 years. This is probably the lowest period that should be assumed on a saw-timber rotation in the Southwest, where considerable time must be allowed for restocking. Ties might be obtained in as low as 120 years after the first cut.

Yields in volume are even more speculative than the time required to produce trees of merchantable size. Assuming that under minimum measures required to maintain a forest cover the stands will seldom be more than half stocked and usually below this standard, the yields will be low. For the periods which have been indicated as necessary to attain the diameters required for saw timber, the acre yields in the three types may be estimated as follows: Ponderosa pine type, 3,000 to 5,000 feet board measure; Douglas fir type, 4,000 to 8,000 feet board measure; Engelmann spruce type, 4,000 to 6,000 feet board measure.

MEASURES NECESSARY TO PRODUCE FULL TIMBER CROPS

The measures necessary to produce full crops of timber are in a general way the same as those outlined under Minimum Measures to Keep Forest Lands Productive, except that they go farther and contemplate more intensive application. Under the measures representing minimum requirements, ultimate maximum yields and public welfare are subordinated to immediate returns to the owner. A program providing for the growing of full timber crops in this region

must subordinate direct and immediate income to ultimate returns both direct and indirect, viewed from the standpoint of public interest.

Except for a relatively small area in the Black Hills, it is not contemplated that private enterprise will engage in forestry to any great extent in the region covered by this bulletin, and for this reason the discussion in the following pages is directed primarily to those responsible for or interested in the management of forest lands in public ownership. The standards here advocated aim to go a step beyond present practice in the national forests, keeping in mind present economic limitations but at the same time anticipating a gradual removal or modification of these limitations. It is even possible that future economic conditions will justify standards of silviculture on the most accessible lands higher than those contemplated in this bulletin.

A great opportunity for improvement over past practice lies in better stocking of the forests. Full timber crops cannot be grown on land that is only partially utilized. Forests throughout the region are bearing light crops because they are or have been understocked. Forest management is handicapped because the stands with which it has to deal are, if not actually understocked, made up largely of trees which are either too old or too young to contribute effectively to the volume increment. One of the most fruitful lines of endeavor in silviculture now is to manage uncut forest with a view toward encouraging advance reproduction and building up the younger age classes so that when the mature timber is harvested there will be left a thrifty young growing stock properly balanced as to age classes. When it is considered that large areas will not be cut within 50 years the excellent opportunities for this kind of improvement are apparent.

The factors which man can control in the production of larger crops of timber are fire, cutting, slash disposal, logging, grazing, insects, mammals and birds, and diseases. Measures to control these factors will be discussed in the following pages. In applying these measures it should be borne in mind that successful forestry, like any other industry, calls for more than perfunctory compliance with rules and regulations. It calls for constant observation and study with a view toward meeting every contingency in the right way and at the right time. In growing crops under a great diversity of conditions, and under many uncertainties of climate and biotic influences, the best laid plans will need to be modified from time to time. Moreover, our knowledge of the requirements of forest trees and stands is far from complete, and any program of forest management must provide adequately for research. All of this presupposes a scientifically trained and well-organized personnel.

FIRE PROTECTION

The standards of and the organization for fire protection outlined under Minimum Measures to Keep Forest Lands Productive are essentially those of the Forest Service in the southwestern region at the present time. Full compliance with those measures should reduce the size and number of fires to a point where they will cease to be a serious limiting factor in forest production. It is feared, however, that an agency whose aim is merely to maintain some sort of forest cover would fall far short of the required suppression standards. Experience in the Forest Service up to a few years ago showed that

a considerable percentage of the large fires was attributable to avoidable errors on the part of individuals directly responsible for fire suppression. Gradual tightening up of the organization, better trained personnel, improved equipment and transportation facilities, and a better understanding of fire problems have brought about marked improvement and may be expected to bring still further progress. It is only this highly developed type of organization that should be considered in a program which aims at the production of full timber crops.

Reference has already been made to the increased fire hazard due to the presence of slash after cutting. As large continuous areas are cut over the difficulty of controlling fires under extremely unfavorable weather conditions will increase. To avoid the possibility of extensive conflagrations, it may become advisable to break the continuity of slash areas by making an intensive clean-up of slash on extra-wide fire lines. If reproduction is successful, the accumulation of leaf litter and the susceptibility to crown fires in the sapling and pole stages will constitute an added hazard. Under these conditions even the complete removal of slash may not create adequate fire lines. This is a problem to be worked out by investigation and large-scale experimentation in administrative practice.

A factor to be counted upon increasingly as time goes on is the cooperation and good will of forest users and the general public. These benefits will be realized in much higher degree, however, under high than under low standards of forest production. Notwithstanding an improved public attitude, both education and law enforcement must be important parts of a fire-protection program.

CUTTING

In the presentation of minimum measures for keeping forest lands productive the importance of natural reproduction has necessarily overshadowed all other silvicultural aims. In a program which contemplates growing full timber crops, even greater precaution will be taken to guard against deficient regeneration; to this end advance reproduction will be a primary objective in the management of virgin forests, and in cutting more and larger seed trees will be reserved than are called for under minimum requirements. No less emphasis must be placed on the development of stands after the reproduction stage is past. Whether needed for seed production or not, trees will be left for growth to provide for future cuts at specified intervals. In localities where reproduction is assured without special provisions, leaving a good growing stock becomes the primary consideration in marking, or designating trees to be removed. This is also a major objective on areas where reproduction is sought, and consequently trees are here reserved from cutting for the dual purpose of reproduction and increment.

SILVICULTURAL SYSTEMS

The silvicultural system or standard method of cutting commonly practiced by the Forest Service in the ponderosa pine type is what is known as the group-selection system. As the name implies, it is a selective or partial cutting system based on the conception that the forest is made up of even-aged groups, which is the characteristic condition in the major portion of the Southwest where the system

was developed (fig. 17). The first step is to mark for removal all overmature, diseased, defective, or otherwise undesirable trees. The mature class is also removed except as individual trees are retained for seed production or to avoid large vacant spaces (fig. 18). The number needed for seed obviously depends on the presence or absence of adequate advance reproduction. Usually entire groups of overmature and mature trees are cut and the individuals reserved for

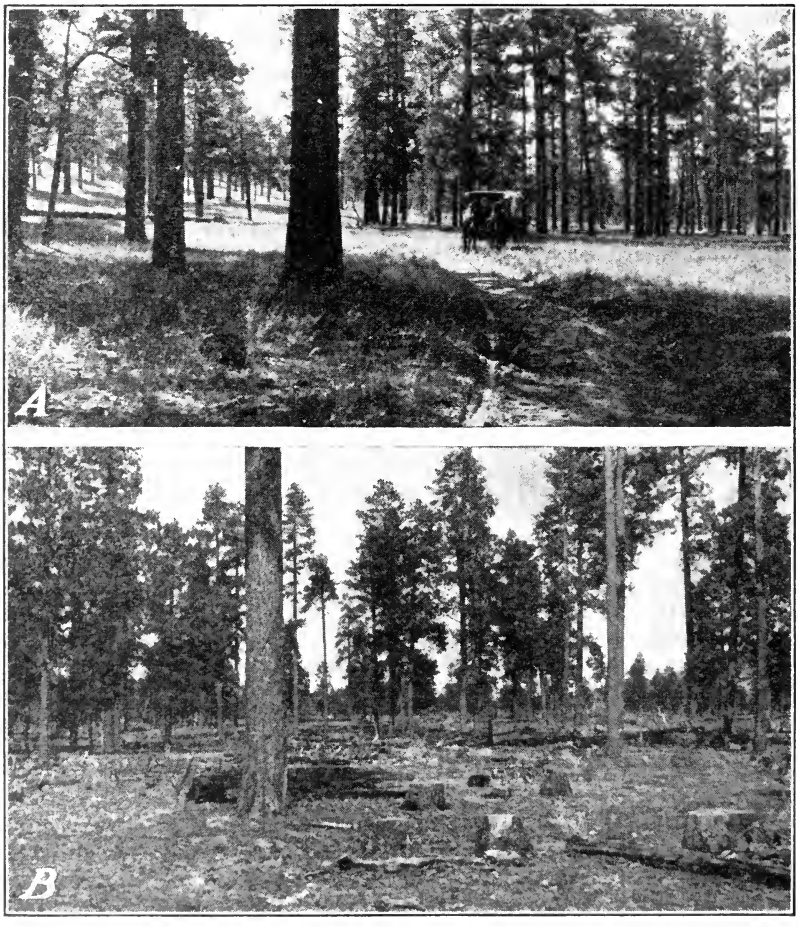

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FIGURE 17.—Ponderosa pine in northern Arizona. *A*, Typical group arrangement of age classes. In applying the group-selection method, the group of large trees in the left foreground would be felled except for 1 or 2 seed trees; the group of blackjacks in the background would be left standing. *B*, A similar stand after cutting. The large trees in the foreground are seed trees; those in the background are mostly blackjacks.

seed are, so far as possible, such as have grown in the open or on the edges of the groups. All blackjacks and intermediates are left except where removal will improve the stand. In dense pole stands, thinnings are executed to the fullest extent that market conditions will permit.

A scattered seed-tree method has been tried experimentally on the Coconino National Forest with good results as to reproduction. An average of 2.5 selected seed trees per acre between 21 and 30 inches

d. b. h. were left as evenly distributed as possible. All other trees above 11 inches d. b. h. were cut. Although the results were generally good, indications are that approximately one more seed tree per acre would have given more uniform distribution of seedlings. As it is, reproduction about equals that where the standard group-selection method was employed. The obvious objection to the scattered seed-tree method is that it removes too much of the growing

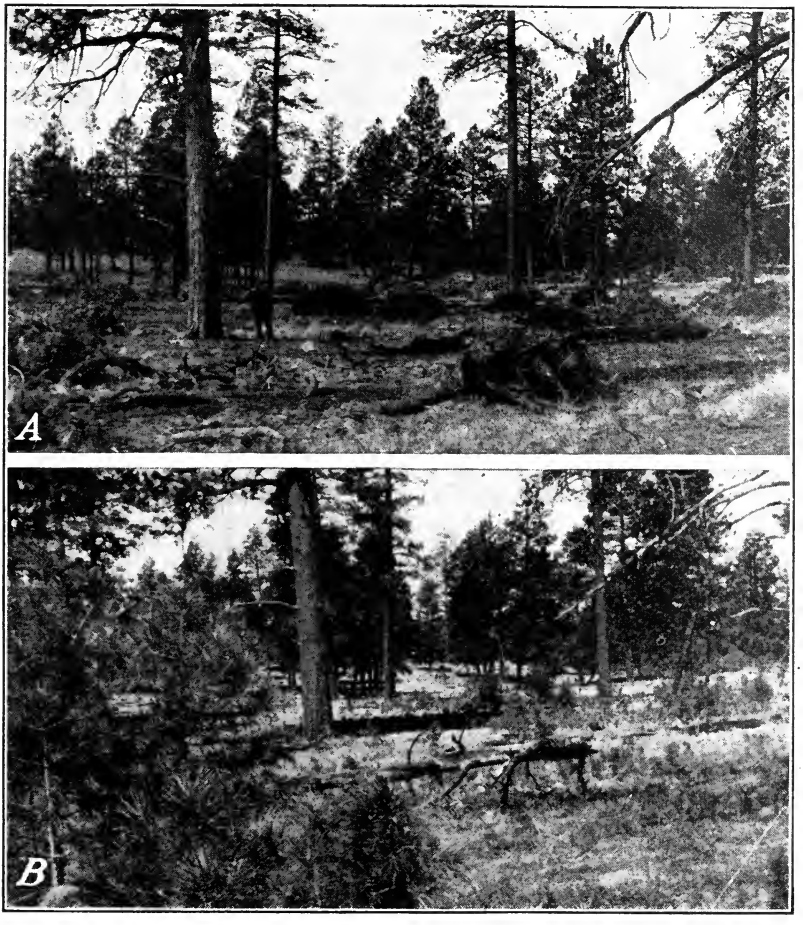

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FIGURE 18.—A, Immediately after cutting by group-selection method in 1907. Groups of blackjacks in the background; large yellow pines left to seed up open spaces. *B*, The same view 20 years later. Most of the ground is now stocked with seedlings 11 to 16 years of age. The broken top in the foreground is from the tree at the extreme right. Note also the persistence of dead branches on this tree.

stock in the blackjack and intermediate classes which by the group-selection method are left to supply the second cut.

The selection of trees to cut or leave can best be done by observation, assuming adequate experience and silvicultural training on the part of the forest personnel. An experienced timber marker knows at a glance to what general age-class a tree belongs. He knows from the size, form, density, and general appearance of the crown

whether the tree is capable of rapid growth when given adequate growing space by removing competition. He also considers seeding capacity, whether the tree is a bad risk from the standpoint of wind and lightning, and whether its increment will be in material of high or low grade.

Essentially the same silvicultural practice has been employed in the Douglas fir and Engelmann spruce types as in ponderosa pine. The main difference is that more trees are left in fir and spruce than in pine stands. The age classes are much the same and commonly occur in groups, very much as in a ponderosa pine forest, although the groups tend to coalesce or sometimes give way to even-aged stands of considerable extent. These even-aged stands constitute a problem, particularly in spruce, because they are usually dense and have a tendency to become deadlocked, slowing down the growth of the entire stand or group. Where there is a market for ties and mine props the situation is improved somewhat, although the groups in need of opening up are mostly below the size, and mine props have a very limited demand. Thinnings on a crop-tree basis may afford a solution.

Extensive areas of Douglas fir, white fir, alpine fir, corkbark fir, and Englemann spruce in the high mountains are, because of transportation difficulties, better adapted to a tie crop than to a sawtimber crop. Hewn ties are more readily made from trees between 11 and 15 inches in diameter than from those of larger dimensions, and this tends to influence the cutting toward a diameter limit. Where natural reproduction comes easily ties may be the best crop, but provision should be made for utilizing the larger trees in the form of lumber or sawn ties. Even on a tie rotation, it would probably be necessary in most sections to grow some trees larger than hewn-tie size in order to insure an adequate seed supply. At the present time some of the species are not accepted for railroad ties, but it is probable that in the course of time the objections to these species can be removed.

SECURING REPRODUCTION

A program of intensive forestry must assume advance reproduction to the fullest extent that the density of the stand will permit, since without such reproduction considerable portions of the ground will lie idle anywhere from 10 to 30 years after cutting. But it is equally essential that every silvicultural program provide adequately for reproduction after cutting. Even though all available space is occupied at the time of cutting by seedlings or young trees, so that substantial progress has been made on the next rotation, the removal of dense groups of timber may leave considerable patches unstocked, and additional strips and patches may be denuded by the logging operation (fig. 19). Moreover, even under the best practice, there will occasionally be areas on which advance reproduction for some reason or other has failed, as, for instance, when a ground fire has swept through. Deferred cutting, to allow reproduction to be completed, is advisable if the areas are large; but such delay is not always practicable.

Whether seed requirements will be met automatically by the trees left for future growth, or whether additional seed trees are needed, is a matter which the forest officer must decide for each area individually. It has been determined on the Colorado Plateau that, where

advance reproduction is lacking, four seed trees of more than 20 inches d. b. h. per acre are required. Under conditions of partial advance reproduction, the number may be reduced in proportion to the area in need of stocking. Similar requirements would apply to southern Colorado. In northern New Mexico and elsewhere in the Southwest where conditions are very favorable for reproduction, the minimum diameter may be reduced to 18 inches. In the Black

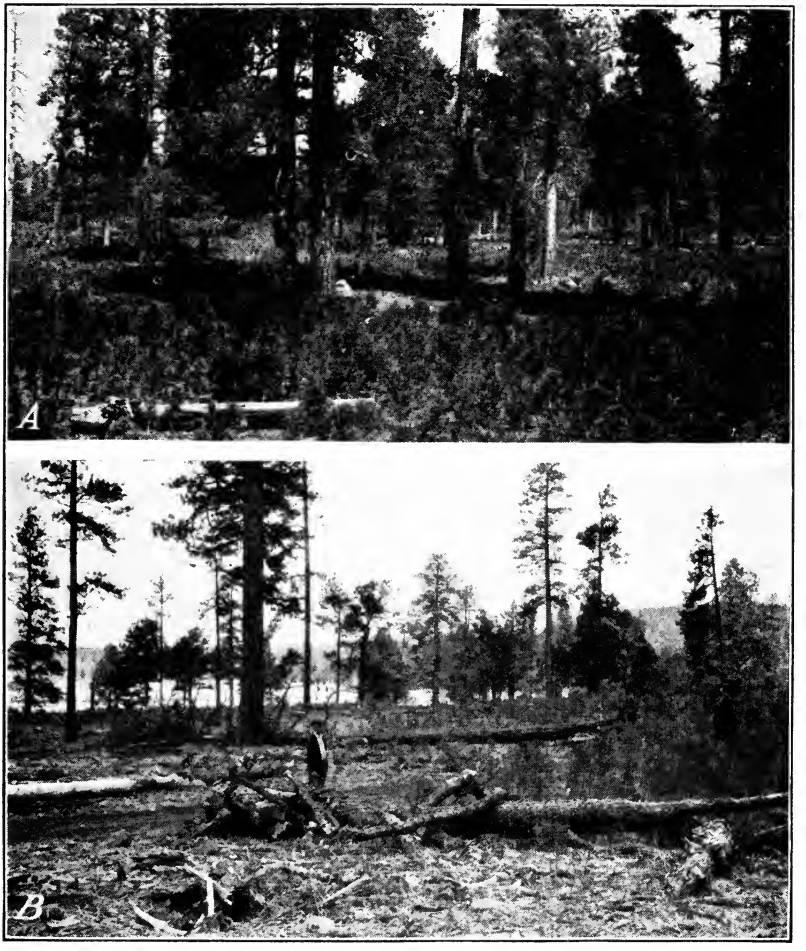

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FIGURE 19.—*A*, Advance reproduction in uncut stand of ponderosa pine; *B*, a stand in which advance reproduction was considered good before cutting but in which cutting left large vacant spaces where tree groups formerly stood. The large trees were left to seed up these spaces.

Hills, seed trees as such are required only in exceptional instances, as on some rather extensive limestone areas where stands have been thinned by bark beetles and reproduction has failed. Since these failures are plainly not due to a lack of seed they do not furnish a clue as to the number and size of seed trees required.

Selected seed trees should be located, so far as possible, with reference to areas in need of restocking. Large trees scatter seed in effec-

tive quantities over distances of 100 to 200 feet, depending on wind direction and velocity. A single tree will not usually cover adequately a circle of this radius, but it is reasonably certain that if 3 or 4 seed trees per acre are spaced more or less uniformly they will cover practically all of the area effectively in the course of several weeks' seed fall.

In the Douglas fir and Engelmann spruce forests the number of immature trees of seed-bearing size is usually sufficient so that if adequate provision is made for a balanced growing stock and for protection of the soil, few seed trees, as such, need be left. As a general guide, the minimum number in the Douglas fir type should be 6 trees over 16 inches d. b. h., and in the Engelmann spruce type 8 trees over 14 inches d. b. h. In the border region, where Douglas fir tends to large dimensions, the minimum should preferably be raised to 18 inches d. b. h. If the stand is deficient in poles and saplings, the above numbers may have to be increased in order to provide adequate cover.

From all standpoints, considering seed yield in relation to wood capital invested, growth possibilities, and susceptibility to loss, ponderosa pine between 20 and 25 inches in diameter and somewhat smaller Douglas fir and Engelmann spruce are regarded as the most efficient seed producers. If the desired number of healthy, full-crowned trees are not to be found within a specified diameter range, it should be realized that diameter is after all only a guide and not a final criterion. An experienced timber marker selects seed trees mainly from the size and appearance of the crown, knowing that, other things being equal, seed-bearing capacity as well as growth capacity is proportional to the area of exposed leaf surface and space for root expansion. The same criterion determines the number of trees per acre that he must leave. Each tree should be studied individually. In practice, a few seed trees of ponderosa pine will be up to 30 inches in diameter and others below 20 inches.

In overmature or diseased stands of ponderosa pine there will be areas on which the required number of good seed trees is not available, but often this can be compensated by increasing the quota within effective seed-carrying distance, or not to exceed 300 feet. A compromise in numbers is preferable to leaving trees that are plainly on the decline and cannot, therefore, contribute much to the yield of seed or timber. This problem becomes particularly troublesome in stands infected with mistletoe, since infected trees not only decline rapidly but spread the infection to healthy young trees. Complete eradication of mistletoe may mean practically clear cutting, including trees below merchantable size. It is important to know that freedom from mistletoe and resistance to its action is most likely to be found in large, mature trees. Thus far, complete eradication of mistletoe has not been attempted because of the expense of cutting unmerchantable material and the risk of denuding areas to such an extent that they will not restock. This subject is treated more fully under the section on control of diseases, page 68.

CARE OF YOUNG STANDS

Having restocked a cut-over area, the next consideration is such care of the young stand as will encourage rapid growth and good form. Assuming protection against destructive agencies, the first essentials are proper spacing and the maintenance of good soil condition.

It is a recognized principle in silviculture that dense stocking in the early stages of a stand is necessary to produce straight, clean stems. Open-grown trees tend to produce large diameters, but with rapid taper and excessive limbiness. These characteristics are developed to the extreme in ponderosa pine on the Colorado Plateau. If limbs are allowed to grow large enough to develop a substantial core of heartwood they persist indefinitely. Photographic records of dead limbs 2 to 3 inches in diameter on ponderosa pine trees near Flagstaff show no visible change after 20 years (fig. 18, *B*). It is too much to expect that even close spacing will promote natural pruning to such an extent as to produce clear stems in young trees; but if the

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FIGURE 20.—Open stands in which limbs are persisting. Trees grown in this manner form knotty, tapering trunks of low market value.

lower limbs die while less than an inch in diameter a fair grade of lumber will result. If they are allowed to attain a diameter of over 2 inches it is safe to say that the lumber will be mostly cull, according to present standards of grading (fig. 20).

If young stands are open enough to permit luxuriant ground vegetation, the soil moisture available for the trees is reduced by the amount used by this vegetation. An ideal condition is one in which the trees are close enough to permit only sparse undergrowth and to form a uniform carpet of needles (fig. 21). The needle litter promotes percolation of water (*9*) and is one of the most effective of erosion

preventives.[16] It is not to be expected that the stand will everywhere be dense enough to maintain a closed canopy, especially in pine; but unless the openings are more than 50 feet in diameter, they will eventually be occupied by tree roots and needle litter from surrounding trees, which, supplemented by herbaceous or shrubby vegetation, will provide adequate soil protection if grazing is not too heavy.

Various attempts have been made to establish a quantitative standard of satisfactory stocking. Obviously, the number of trees per acre does not adequately define the standards unless distribution also is indicated. Moreover, density normally decreases with age. Table 6 indicates for different species what is considered the maximum distance between trees that will result in the formation of satisfactory

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FIGURE 21.—Dense stand in which the stems are cleaning themselves naturally. This is the way long, clear trunks are formed. Note the dense mat of litter and the absence of grass.

stands. Greater density is desirable up to a point where competition will retard growth.

TABLE 6.—*Maximum spacing in southwestern stands to produce trees of desirable form*

Height of tree	Ponderosa pine	Douglas fir	Engelmann spruce	Height of tree	Ponderosa pine	Douglas fir	Engelmann spruce
	Feet	*Feet*	*Feet*		*Feet*	*Feet*	*Feet*
Below ½ foot	2	1	1	7 to 12 feet	6	5	4
½ to 1 foot	3	2	2	13 to 20 feet	7	6	5
1 to 3 feet	4	3	3	21 to 30 feet	8	7	6
4 to 6 feet	5	4	4				

[16] It is a matter of common observation in the Southwest that old gullies in young pine thickets are being sealed by needle litter. These gullies evidently were formed during periods of overgrazing when the pines were too small to interfere with the passage of livestock or to build up a mat of needles. In more recent years suppression of herbaceous vegetation has rendered the areas unattractive to stock, and at the same time the needle cover has increased in depth, partly because of less trampling and partly because the annual fall of needles increases as the trees grow larger.

Overdense stands are the exception, taking the region as a whole, but they do constitute a problem in some localities. In the Black Hills, young stands of ponderosa pine are commonly so crowded that growth stagnates. Even on the Colorado Plateau where the problem is usually one of deficient stocking, ponderosa pine sapling stands are sometimes so dense that the stems become too slender to support the crowns. The most serious condition is found in spruce, because of the greater persistence of individuals in subnormal state and the consequent prolongation of the struggle for supremacy.

On an experimental plot of 40-year-old ponderosa pine on the Prescott National Forest in Arizona, thinning has increased the average diameter growth of the remaining trees by 0.2 inch in all diameter classes during a period of 5 years. This was accomplished by removing the underdeveloped, defective, or misshapen trees. In this instance the wood removed was sold for poles and fuel, netting a small revenue. Except in the Black Hills, however, there is usually no market for small stems and the cost of thinnings is an outright expense. To what extent this can be offset by increased rate of growth depends upon a number of factors, including the price of labor, the rate of growth attainable, and the value of stumpage when the stand is cut.

Ordinarily, the stand left on cut-over areas will be made up of trees of many ages, from the seedling stage up to mature seed trees. If the cutting has been properly executed this residual stand will have been improved by removal of diseased, defective, misshapen, and crowded trees. In past national-forest practice such removals have been limited to stems of merchantable size. Obviously, this limitation has been a silvicultural handicap. Legislation enacted in 1930, known as the Knutson-Vandenburg Act, permits utilizing receipts from the sale of timber on Federal lands for planting or removing undesirable trees in order to improve the future stand of timber on the cutting area. The removal of mistletoe-infected and other diseased trees, release cuttings, and the thinning of overdense young stands may be done under this act, within certain fiscal limitations.

The Emergency Conservation Work Act (Mar. 31, 1933) and the National Industrial Recovery Act (June 16, 1933) furnished unprecedented opportunities for improvement of young timber stands. Not only have extensive areas been thinned and pruned, but the concentrated thought of many foresters engaged in this work has led to a clearer conception of its purpose, possibilities, and limitations.

At the outset it was recognized that costs should be reasonably commensurate with expected returns. In view of uncertainties in regard to the effect on yield and still more as to future timber values, no attempt has been made to fix a definite cost limitation. Actual costs on some 20,000 acres in the southwestern region in 1933 varied greatly, but in the main were around $6 per acre, with a trend toward lower levels.

In 1934 costs were further reduced by limiting cutting to the release of so-called "crop trees" or those which may be expected to figure in the final crop, and the removal of diseased and "wolf trees." Since the number of trees which reach maturity in one rotation seldom exceeds 40 per acre, it has been estimated that 80 crop trees would provide an ample margin for mortality on average pine sites. On Douglas fir, Engelmann spruce, and the better pine sites, more than 80 trees would probably be advantageous. Only crop trees are pruned.

In releasing crop trees, the primary purpose is to give them enough growing space to insure their dominance. It is not considered desirable to thin so heavily as to prevent future crowding because this would encourage ground vegetation and stimulate coarse limb growth. In order to maintain a rapid rate of growth, the crop trees should be favored by periodic removal of competing trees.

To what extent results will warrant such practice cannot be stated at the present time. Plots have been established on which permanent records will be maintained with a view toward answering this and many other questions.

SUSTAINED YIELD

Directly associated with the growing of full timber crops are orderly harvesting and marketing. The forests within a geographic unit, and as far as possible within each community, should generally be so managed that timber yields from year to year will be kept at a constant or rising level. Such a sustained yield lends stability to the forest organization, to the timber market, and to local industry. Under this principle the annual cut may vary with market conditions, but the cut during a period of years must be on a basis in harmony with the yield or permanent productive capacity of the forest.

Sustained yield is a vital economic factor in communities dependent in large part upon forest industries. A lumber manufacturing plant employing 100 or more men is an important business asset to any small town, and if for any reason such a plant must cease operations, even temporarily, the community suffers. Market depressions may necessitate temporary shut-downs, but in a well-regulated forest there should never be a shut-down for want of raw material. There is no greater tragedy in American industry than the familiar one of towns built up on a thriving lumber industry and subsequently abandoned when the last log went through the mill.

An obvious requisite for sustained yield is a proper gradation of age classes. Theoretically, the age classes within a unit of management should be as many as the years in the rotation. In practice, however, it is customary to group trees by 20-year age classes. As has been pointed out, a characteristic arrangement of trees in the ponderosa pine forests, especially on the Colorado Plateau, is in even-aged groups, varying in size but usually between one-tenth and one-half acre. The oldest age classes are represented by remnants in the form of scattered, overmature, dead, or dying trees, usually more than 300 years old. A somewhat younger but still overmature class will be found in groups still intact but disintegrating. Most of the mature timber is in even-aged groups between 200 and 250 years old. Distinction between mature and overmature or very old classes is possible from the appearance of the crown, the overmature class usually showing marked signs of decline. A class of blackjacks about 150 years old occurs in well-defined groups in practically all ponderosa pine forests in the Southwest. Younger age classes represented by large poles, small poles, and saplings, also occur more or less abundantly.

ROTATIONS AND CUTTING CYCLES

Management plans contemplate a saw-timber rotation, or profitable growth limit, for ponderosa pine of 150 to 200 years, depending upon locality and site quality. On the better sites a rotation of about 150 years will produce the maximum annual yield in volume, but,

considering quality as well as quantity of yield, a 200-year rotation may prove more profitable. This depends in large measure upon what future markets are going to demand. On some of the poorer sites there are indications that the soil is not capable of carrying well-stocked stands to maturity. Growth is rapid up to a certain age, and then, probably in consequence of prolonged drought and bark-beetle attacks, the trees die in large patches. On such areas a shorter rotation may become necessary. The cutting cycle, too, will be influenced by local conditions and by future market demands. Present indications point to three cutting cycles of about 60 years each. In the Black Hills, present plans call for a rotation of 140 years and four cutting cycles of 35 years each. Although Douglas fir and Engelmann spruce in the Southwest will produce greater volumes than ponderosa pine in a given time, it is uncertain whether they can be handled on shorter rotations because the greater density of the stands makes for smaller diameters. This is especially true of spruce.

From a silvicultural standpoint short cutting cycles will prove most efficient because they tend to relieve competition and also make it possible to salvage a large amount of material which would otherwise be lost. Where extensive areas await the first cutting, a light first cut, to be followed by a second cut in a period less than the regular cutting cycle, would hasten the removal of overmature timber, encourage advance reproduction, and place virgin stands in a better silvicultural condition generally. As pointed out in the early part of this bulletin, however, logging operations call for a certain minimum volume of timber per acre in order to justify overhead expenses such as railways and truck roads. It is probable that in the more accessible localities the cutting cycles will be relatively short and considerable quantities of dead and dying timber will be removed between the regular cuttings.

In ponderosa pine stands in the Southwest that have been logged or are now being logged for the first time, the next cut probably will consist largely of trees 200 years old or older, including the present blackjacks, intermediates, and the surviving mature yellow pines left for seed. The third cut will be made up largely of the present pole stands down to about 60 years of age and such older trees as may be reserved in the second cutting. The volume available will be more or less problematical because on many areas there is a dearth of trees in the lower age classes.

The solid-line graph in figure 22 represents a desirable distribution of age classes in a cut-over stand. As is to be expected, the number of trees of the larger diameters has been reduced by logging. Middle diameters ranging from 14 to 22 inches are well represented, and below about 11 inches there is a sharp rise, indicating that reproduction has been going on during the past 75 years. A great preponderance of numbers in the lower diameter classes is necessary both in order to provide the much-desired dense stocking in youth and in order to offset the normal high mortality in young stands.

The broken-line graph represents the very undesirable actual condition in many instances. There is a preponderance of diameters over 16 inches, which means a good second cut, but the deficiency in diameters below 11 inches augurs ill for the third cut.

LOGGING

Although a full compliance with the minimum measures already prescribed for preventing excessive damage to young growth and reserved trees will fulfill the requirements under intensive management, such compliance is impossible without close supervision on the part of forest officers and whole-hearted cooperation on the part of operators and their employees. As forest management becomes more intensive and utilization more complete, more refinements in logging practice can be put into effect than seem practical now. If such refinements greatly increase the cost of logging, however, the

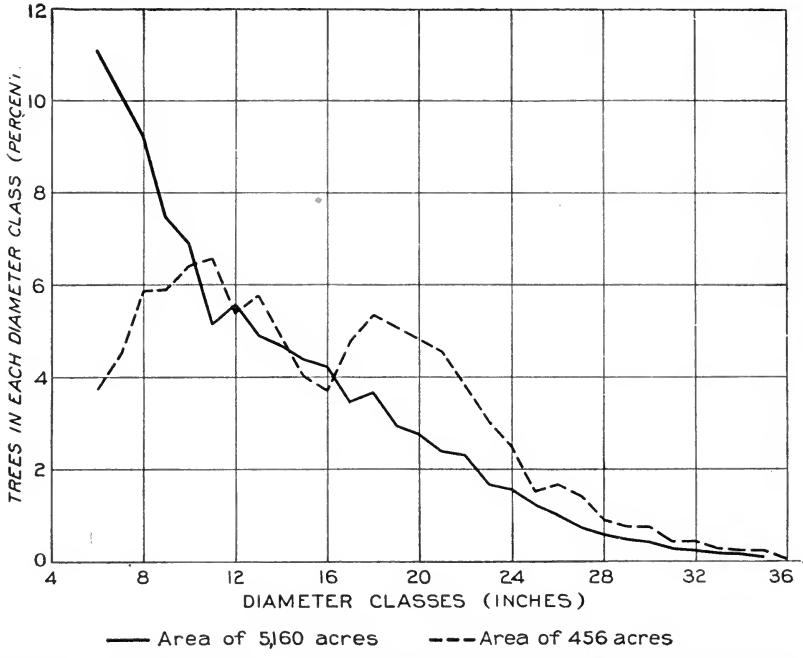

FIGURE 22.—Diameter distribution on two different cut-over areas of ponderosa pine on the Coconino National Forest, Ariz.

extent to which they can be practiced will depend upon timber values.

Opportunities for decreasing logging damage are to be found in both felling and skidding operations. Where the timber occurs in groups the present practice is to fall the trees out, away from the center of the group, into the openings where advance reproduction is at its best. Usually there is little or no reproduction under and for 20 to 40 feet around the tree groups, and therefore this would be the ideal place to fall the trees if it could be done. Not only would damage decrease, but the cost of brush disposal would also decrease. If reproduction is dense, and if the trees are not felled too close together, the thinning effect may be beneficial. On the whole, however, considerable damage usually results from felling trees into young growth, and this increases with the size of the young trees. Skidding operations increase the toll. The damage by this cause is usually underestimated because sufficient weight is not given to

bruising of stems and damage to roots by the cutting and packing effect of wheels.

Much can be accomplished by educating loggers to appreciate the value of young trees and the consequences of soil abuse; but the ultimate solution lies in careful planning and direction by forest officers.

Far-reaching benefit can be realized by increasing the efficiency of the logging operation itself. Lowered logging costs and better utilization would make possible silvicultural measures which are not practical now because of the narrow margin between cost of production and selling price. Added transportation facilities through the development of forest roads promise to be an important factor. Another is the stabilizing influence of continuous operation under sustained yield. More silviculture in logging will result in heavier yields per acre and better lumber grades, which will in turn be reflected in lower logging costs.

SLASH DISPOSAL

Slash disposal as a minimum measure for maintaining productive land was discussed wholly with regard to fire protection. Where protection is a first requisite, intensive forestry, which aims at higher standards of production, will on the whole call for even more use of piling and burning. On the other hand, it may be laid down as a general rule for the ponderosa pine type that piling and burning of slash beyond the requirements for fire protection is seldom warranted. Also, more complete utilization in the future should decrease the amount of slash to be disposed of. If the limb wood above a diameter of 2 inches could be utilized, the slash problem would be greatly simplified. Intensive forestry presupposes such control of grazing that the leaving of slash is not warranted as a protection from livestock.

Wherever the soil is deeply covered by litter, and in dense cover of tall grasses, natural reproduction is aided by burning slash. This condition is quite common in the Douglas fir and Engelmann spruce types. Here, however, it becomes necessary to weigh the benefits in favor of young seedlings against the damage to older trees by fire. Often the saplings and young trees are so dense that brush piles cannot be burned without doing excessive damage, and since the fire risk is usually low it may be better to leave the slash and rely entirely on fire protection. The same situation is sometimes encountered in the ponderosa pine type, but here it is usually possible to burn brush piles without excessive damage. Where advance reproduction of ponderosa pine is present, it is exceedingly desirable as a protective measure to burn the brush unless the fire risk is low. In the Black Hills, where advance reproduction occurs almost invariably, piling and burning is standard practice.

As has already been pointed out, slash applied in moderate density distinctly favors reproduction of ponderosa pine on bare soils subject to severe desiccation. Overgrazed clay flats, common on the Colorado Plateau, are a typical example of sites on which slash should be scattered for soil protection. This should be done also on the more or less bare cobblestone areas where the surface soil has been washed away. It is standard practice in the national forests throughout the region, including the Black Hills, to scatter slash on all sites subject to severe erosion and to throw large quantities into unused roads and in gullies.

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It is evident from the foregoing discussion that the slash-disposal problem is exceedingly complex. Where the situation demands great caution, the protective measures of slash disposal described on page 40 should be followed. Because of the varying conditions encountered it is seldom possible to formulate rules that can be applied uniformly to a cutting area. The forest officer in charge of a timber sale should understand the principles of slash disposal and should study each area carefully in order to apply the right method on every individual spot. This flexible system is being practiced on the national forests in the Southwest under what is termed "diversified slash disposal."

GRAZING

Past grazing damage to forest reproduction in the Southwest, together with some of the factors involved and remedies applied, has already been discussed in considerable detail. Briefly stated, grazing was for many years the dominant controllable factor in the failure of reproduction on extensive areas; but as a result of improved range management, involving large reductions in and better distribution of stock and shortening of the grazing season, serious damage has to a large extent disappeared. Relief from grazing damage has put new hope into silviculture. Where the lessons in grazing learned from past experience are applied, pine forests can now be cut with assurance that under proper silvicultural and protective measures the cut-over land will restock naturally. Notwithstanding this favorable turn, enough damage persists to show that grazing is still a factor to be reckoned with, and that it calls for special attention in a program that contemplates growing full timber crops.

Good range management should be the main reliance of the silviculturist for prevention of damage by livestock, but he should not depend on it absolutely, because many factors still imperfectly understood influence the feeding habits of livestock. Moreover, it is too much to expect that range management will be perfect where a single ranger is responsible for all administrative activities on many thousands of acres. Cut-over areas should receive special supplemental attention. Even though advance reproduction may have been good before cutting, unstocked areas of considerable size will appear after cutting, and there will be a tendency for livestock to concentrate in these areas.

Because of the susceptibility of very young seedlings to complete eradication, they should be guarded with great vigilance. If, as sometimes happens, 20,000 or more seedlings per acre appear at one time, the landowner should realize that he is confronted by an opportunity which may not be repeated in several decades. For reasons not fully understood, seedlings less than 2 years old have suffered very little since 1926, even on areas where older seedlings show damage. Lighter stocking affords a partial but not complete explanation of this situation; it is possible that the older seedlings now fairly abundant in most places are browsed in preference to very small seedlings. But until the true explanation is known, it should not be taken for granted that such great losses as were experienced in 1919, 1920, and 1921 cannot be repeated. The surest way to detect damage to small seedlings is to lay out a number of plots and make counts of seedlings about once a month through the grazing season. If at any

time as many as 5 percent of the seedlings on 10 percent of the total area are killed or severely injured, the situation calls for prompt action.

After the seedlings are 2 years old they are less likely to be killed unless browsed repeatedly. Although damage to this class of seedlings is not to be ignored, a reasonable amount may be tolerated. Where the line should be drawn depends upon a number of circumstances, such as number of seedlings on the ground and the need for relatively heavy grazing in order to check competing vegetation. As an average figure, 5 percent damaged each year on 10 percent of the total area is not excessive.

The possible benefits to forest reproduction by grazing should be weighed against seedling damage. Tall, dense grasses and weeds offer severe competition to young seedlings for light and moisture. This is very evident on areas occupied by Arizona fescue (fig. 12). On stump patches almost any kind of vegetation will, if undisturbed, crowd out pine seedlings unless the seedlings become established first. On the other hand, seedlings which once gain possession of stump patches make the most rapid growth observed anywhere (fig. 23). On bunch-grass lands and on stump patches in bunch grass or elsewhere, grazing should be rather heavy until a good seed crop germinates, and should then be restricted in order to avoid seedling damage. The splendid stand of 1919 seedlings on most of the Colorado Plateau undoubtedly was favored by the heavy grazing of preceding years. If the substantial stock reductions made after 1924 had been made in 1920, the 1919 seedling crop would undoubtedly have been much better generally than it is. Substantially this method of control was successfully applied on small areas in 1914–15 and again in 1919–20 (fig. 24).

If for any reason range management fails to bring about adequate and timely control of damage to forest reproduction, an effective remedy is available in temporary or seasonal exclusion of stock from the areas affected. Leader browsing can be practically stopped by keeping stock off the range through June and early July until the summer rains begin. Needle browsing can be greatly decreased by removing the stock not later than September 30. Both of these measures presuppose conservative grazing and proper handling of stock. If young seedlings are being killed in excessive numbers the situation calls for emergency measures; stock should be excluded until the seedlings are 2 years old, and after that seasonal exclusion should be practiced.

Forest grazing in the Southwest should be regarded more as a silvicultural measure than as the utilization of a forage crop. When young seedlings require special protection, temporary sacrifice of the forage crop is justified. When reproduction can be aided by temporary heavy grazing, this too is justified, provided that precaution be taken against excessive soil deterioration. Objections to both measures may be raised on the ground that they interfere with grazing administration and with the stock industry. This need not be so if adequate foresight is exercised by forest administrators. Provisions should be made, by water development and other improvements, for moving stock from areas requiring light grazing to those requiring

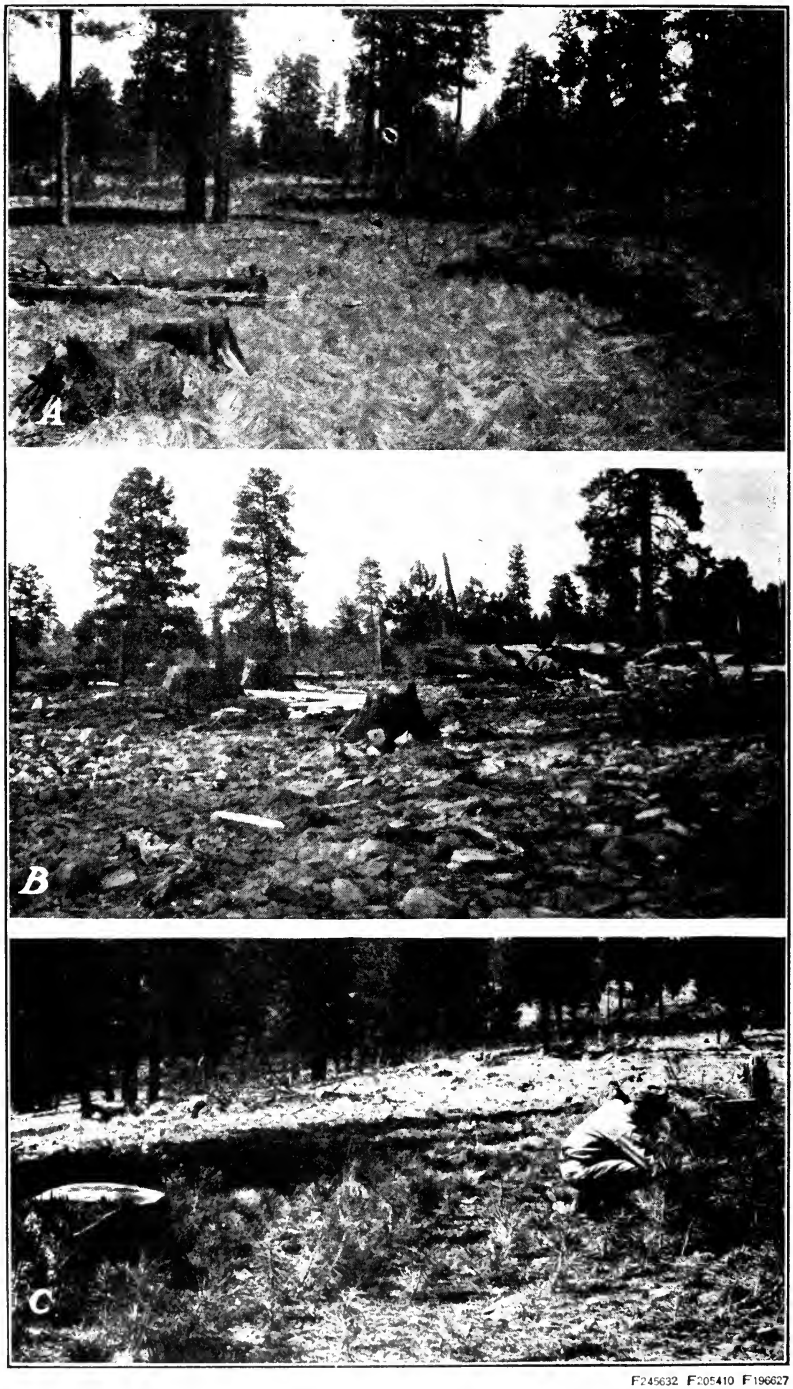

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FIGURE 23.—Effect of grazing on reproduction in stump patches (the spaces immediately around stumps): *A*, No grazing; no reproduction 20 years after cutting; dense bunch grass has taken possession. The groups of seedlings in the distance have come up where grass is of only moderate luxuriance; *B*, extreme overgrazing; nearly all seedlings destroyed; *C*, close grazing, but the seedlings, 6 years old, have escaped serious damage. Seedlings of the same age are abundant but much smaller outside of the stump patch.

heavy grazing for silvicultural reasons. Every national forest should have reserve range for use in emergencies. After an orderly system of forest management is once in effect, the areas to be restocked at any one time will not be large enough to affect more than 2 or 3 grazing allotments in a national forest. It must be expected, however,

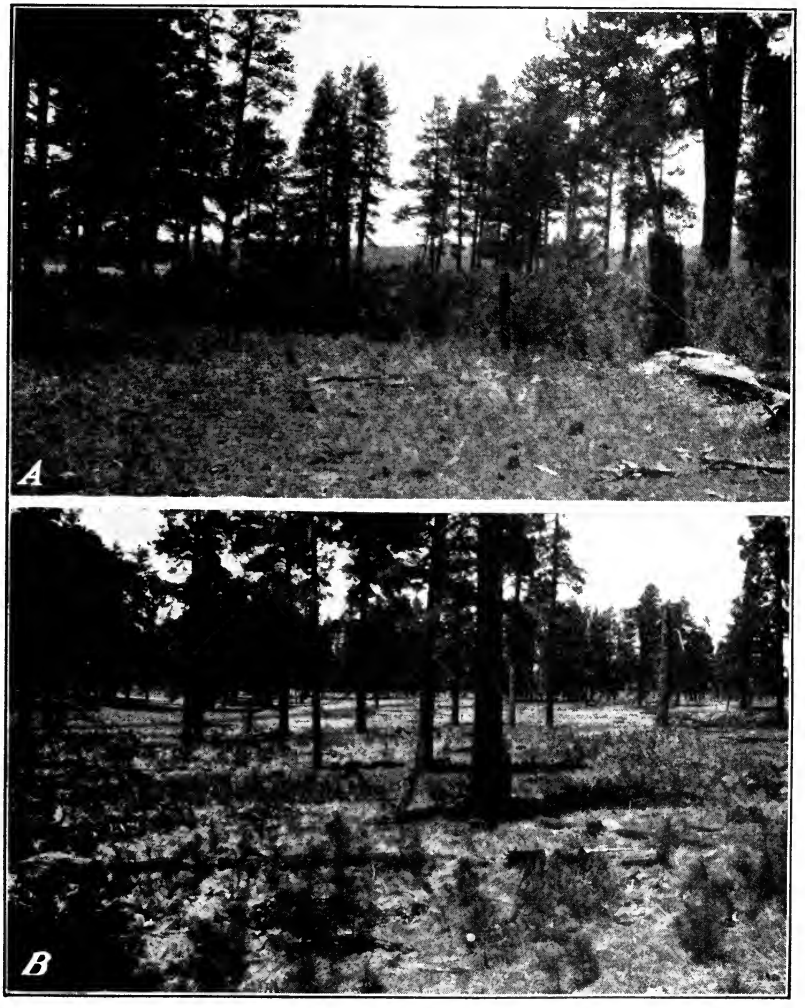

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FIGURE 24.—*A*, Good reproduction of ponderosa pine under controlled grazing. Fence built in 1915 following good germination in 1914; moderate grazing by cattle and horses allowed inside pasture; outside (foreground), heavy overgrazing killed most of the seedlings and damaged the others; under lighter grazing since 1929 the surviving seedlings have begun to grow. *B*, Good reproduction under continuous grazing. Germination in 1919; many seedlings were killed in 1920, but stock was reduced in 1921 and again in 1925; reproduction has taken place entirely after cutting.

that the establishment of dense sapling and pole thickets will decrease forage production. Unless this is anticipated and provided for, a time will come when the number of livestock on areas of second growth will exceed the carrying capacity, to the detriment of associated areas in the process of regeneration.

CONTROL OF INSECTS, BIRDS, MAMMALS, AND DISEASES

Intensive forestry is not possible without adequate control of animal life and pathological agencies which may adversely affect the forest. Since control measures in these fields are of a highly specialized nature, it is not the purpose to discuss them here beyond pointing out some of the conditions under which control may be necessary. It is the policy of the Forest Service in dealing with these problems to enlist the cooperation of the Bureaus of Entomology and Plant Quarantine, Biological Survey, and Plant Industry, within their respective provinces.

INSECTS

Such insect pests as the spruce budworm, hemlock looper, and tip moth, though their activity is responsible for much damage, have not been successfully controlled on a large scale. Baumhofer [17] has employed the parasite *Campoplex frustranae* in the control of *Rhyacionia frustrana bushnelli*, a western form of the Nantucket tip moth, in ponderosa pine plantations at Halsey, Nebr.; but, unfortunately, this parasite has not proven effective against the Southwestern tip moth, *R. neomexicana* Dyar.

Peeling of the infested trees is sufficient to check the attacks of the Black Hills beetle and some other bark beetles, but burning the bark is practiced for such forms as *D. barberi* (Hopk.) and *D. convexifrons* (Hopk.). It has been pointed out by the Bureau of Entomology and Plant Quarantine that in a going logging operation bark beetles are in large measure controlled automatically, because felled trees become trap trees and the larvae are destroyed when the logs go through the mill. If for any reason the logging operation stops, an abnormal amount of damage may result. In localities subject to *Ips* attacks, great care must often be taken in the pine type to burn slash and peel the bark from large material left in the woods after logging. A common error is to clear rights-of-way for roads and building sites without adequate precautions against *Ips;* the consequence is often the killing of young trees highly prized for scenic purposes. Fortunately, the activity of *Ips* is rather localized. It appears to be worst in the lower edge of the pine type and following dry years.

BIRDS AND MAMMALS

All evidence at hand indicates that control of seed-eating rodents is desirable, not to say necessary, under certain conditions. On areas which must be restocked after cutting, reduction in numbers of mice, chipmunks, and ground squirrels would undoubtedly hasten the process of restocking. In artificial reforestation by direct seeding, control of rodents would be one of the first steps in the program. Poisoned grain prepared by the Bureau of Biological Survey has been used to reduce the numbers of mice and chipmunks.

Birds, as a class, are to be regarded as beneficial through their activities against insects and rodents and in disseminating tree seeds. Although instances of birds injuring young conifer seedlings are not lacking, such damage is undoubtedly outweighed by the benefits of insect control. It is well known that most species of hawks and owls are active in killing rodents.

[17] The results of this work by L. G. Baumhofer have not yet been published.

Wherever the porcupine is present in large numbers, control measures are essential to the production of full timber crops. The Bureau of Biological Survey (*4*) has developed effective control methods, including use of a poison bait, consisting essentially of strychnine and salt, that is being used with good results on the Coconino and Tusayan National Forests of Arizona. Control measures are also urgently needed in northern New Mexico, Colorado, and the Black Hills.

The idea that large forest areas can be set aside and maintained permanently as game sanctuaries, destroying predatory animals and permitting the game to increase indefinitely, is no longer tenable. Stocking of a range with deer, antelope, and elk must be as carefully adjusted to the carrying capacity of the range as is the stocking with domestic animals. Forest areas which are largely devoid of shrubby growth should be lightly stocked with big game because in the absence of this class of forage they are likely to attack young conifer trees. As soon as the game has increased to nearly the carrying capacity of the range, measures should be taken to insure removal of the normal increase.

On areas set aside for the preservation of native flora and fauna, it would be a mistake to exterminate the predatory animals that are nature's safeguard against overstocking with deer and rodents. Moderate control of predatory animals may be necessary but, without a check on the increase of grazing and browsing animals, the consequent disturbance of natural conditions may be greater than under the usual forms of industrial exploitation.

Any attempt to discuss animal life in relation to the forest is handicapped by a lack of specific information as to the habits of different species. No control operations should be undertaken without carefully weighing beneficial against harmful activities. It is important to consider not only the direct and obvious effects, usually detrimental, but also the indirect effects, such as that of one animal preying upon another, or the effects upon soil and competing vegetation. Even in the case of seed-eating rodents, it is possible that some species are a factor in keeping insects in check. Further studies are needed of the life histories of all animals of the forest, including mammals, birds, and insects.

DISEASES

Of the pathological agencies affecting the forests in this region, those causing decay of wood and the parasite mistletoe are most susceptible of control by means at the disposal of forest management.

There is no known way of checking wood-rotting organisms in a living tree and therefore control measures must take the form of prevention. Heart rots usually gain entrance through dead limbs, so the early natural pruning obtainable in densely stocked young stands should exert a favorable influence. Prevention of fruiting or spore formation should also prove effective. The most important wood-rotting fungus, namely western red rot (*Polyporus ellisianus*) continues to function and fruit after the tree has been felled. However, it generally fruits only on the under side of logs in contact with the ground, and then only if the bark remains on the wood. Effective remedies against fruiting are to peel all logs or limbs over

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6 inches in diameter, char them in brush burning, or keep them off the ground. The last measure can often be effected by limbing in such manner as to leave the bole supported by "prong horns" or stubs of branches.

Unlike heart rots, mistletoe ceases to be a menace when the tree dies. Aside from limited possibilities in removing infected branches, the only known means of controlling mistletoe is to cut the infected trees (*6*). Foresters in the Southwest have been more or less uncertain as to how far it is advisable to carry this measure. In many instances complete eradication means almost clear cutting. In such cases, the old trees, or yellow pines, should be carefully examined for specimens free of mistletoe to be left for seed trees. Young trees free of mistletoe are, of course, also desirable. The fact that a tree exposed to mistletoe has escaped infection indicates that it may be immune, and this suggests the possibility of developing a resistant strain (*2*). If as many as 3 such trees per acre of more than 20 inches in diameter can be left, the removal of all mistletoe-infected trees, including saplings and seedlings, is justified silviculturally. Experience has shown that fairly good reproduction can be obtained with large seed trees in numbers averaging 2.5 per acre. How much farther this reduction might go is problematical. If reproduction is not adequate, planting may become a necessity.

The best solution of the mistletoe problem is to withhold cutting until good advance reproduction is obtained, and then cut everything bearing a vestige of the parasite. The logging operation should be followed by clean-up surveys in order to remove any trees or branches on which mistletoe may have made its appearance. Obviously, the felling of unmerchantable trees is going to cost money. How much of an expenditure is justifiable depends upon many circumstances. Where the cost of thorough eradication is less than the stumpage value of the timber, the expense would seem to be warranted if a fairly good stand of reproduction can be obtained.

It must be admitted, however, that no one knows whether absolute eradication of mistletoe is necessary, and whether a stand once freed of the pest can be kept clean without excessive outlay for control operations.

How rapidly a large area will be reinfected is not known. Birds, squirrels, and porcupines undoubtedly are potent factors in disseminating mistletoe seeds. The whole problem requires further investigation.

Much of what has been said about the difficulties of mistletoe control applies to other pathological organisms. Control operations are always interwoven with economic questions and biological and ecological relationships. The necessity for research suggests itself at every turn. Not only must the life histories of disease-producing organisms be known but their action upon and response to plants, animals, and physical factors should be better known. Research of this character should be supplemented by experimental control operations on designated areas to be kept under permanent record.

PROBABLE YIELDS UNDER GOOD MANAGEMENT

Relatively little attention has been given to determining possible yields in normal or fully stocked stands in this region. This is because such stands in the mature stage are found only on very small

areas and it is not known to what extent they represent a goal possible of attainment on a large scale. As has been stated previously, mature stands of ponderosa pine seldom bear as much as half the volume that the soil can support. This is evident from the large proportion of land within virgin forests that is either unstocked or bears only seedling or sapling growth. It is difficult to find mature, even-aged, fully stocked pine in blocks of as much as an acre. Where such blocks are found on good sites in the Southwest the total volume is usually from 20,000 to 30,000 feet board measure at 150 years, and up to 40,000 feet at 200 years. There is little doubt that yields of this magnitude could be produced on the better sites if it were possible to maintain full stocking throughout a rotation. Still higher yields are theoretically possible in the Douglas fir and Engelmann spruce types.

It may be assumed that under intensive management the stocking and the yields of virgin stands can be greatly improved; but how nearly they can be made to approach 100-percent efficiency is problematical. Fire and overgrazing, the two greatest obstacles to natural reproduction in the past, will probably be controlled in the future, but present indications are that even if these factors were entirely eliminated complete restocking on all the land could not be expected. Moreover, complete stocking in early stages does not insure full crops unless the stocking can be maintained. Insects and disease undoubtedly have operated to reduce the stocking of established young stands, or to hamper their growth. Science may come to the rescue, but control measures cost money. Then there are the droughts, which occupy such a prominent place in the traditions of the Southwest. Granting that only indirect proof exists of droughts severe enough to exterminate or cause the migration of former civilizations, accounts within historic times give a hint of the dangers to which a forest is exposed during a rotation of 150 to 200 years. Though the possibilities of silviculture should not be minimized, it is only fair to recognize its limitations. Making due allowance on both sides, it is safe to assume that present average yields can be increased by 50 percent. Thus, whereas mature virgin forests of ponderosa pine in good state of preservation now yield 10,000 to 20,000 feet board measure per acre at an age of 200 or more years, it is reasonable to expect that under good management the yield can be increased to 15,000 to 30,000, depending on site quality.

Although yield during a rotation is the usual criterion of producing capacity, the forester who is managing many-aged stands is more directly concerned with yield during the cutting cycle. He wants to know how often his forest can be cut over and how much can be removed in each cut. In the Southwest, present predictions of yield usually do not extend beyond the second cut.

Growth studies have been made on cut-over areas in the Southwest by means of 5-year measurements on sample plots over periods of 15 or 20 years.[18] Table 7 gives the volume of growing stock, annual increment, and annual mortality on several plots cut by different methods on the Coconino and Kaibab National Forests. So far as increment is concerned, the main difference between these plots is in the volume of growing stock left after cutting. Mortality is also an important factor. The scattered seed-tree plot has the lowest

[18] Measurements and compilations in tables 7, 9, 10, and 11 by Herman Krauch.

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volume of growing stock and next to the highest mortality, a combination which is reflected in both actual and relative increment. The shelter-wood cutting, which, owing to the character of the original stand, is virtually only a light group-selection cutting, gives the highest yield in board feet per acre, but a lower percentage yield than the standard group-selection cutting. The high residual volume and low net increment percentage associated with a moderate rate of mortality indicate that the trees may be too closely spaced for rapid growth.

TABLE 7.—*Increment and mortality of ponderosa pine in relation to method of cutting and volume of growing stock, Coconino and Kaibab National Forests*

Plot and method of cutting	Area of plot	Length of record	Volume [1] per acre left	Net annual increment per acre [2]		Annual mortality per acre	
	Acres	*Years*	*Ft. b. m.*	*Ft. b. m.*	*Percent*	*Ft. b. m.*	*Percent*
S3, group selection	456	20	3,520	91	2.59	20	0.57
S4, group selection	304	20	2,328	67	2.88	8	.34
S5–I, group selection	139	15	2,846	79	2.78	18	.63
S5–II, scattered seed tree	152	15	1,873	30	1.60	22	1.17
S5–III, shelter wood	112	15	4,510	93	2.06	29	.64

[1] All board-foot volumes are according to the Scribner log scale including only trees 12 inches or more d. b. h.

[2] Net increment is gross increment reduced by the amount of annual mortality. With intensive management most of the dying trees 12 inches or more in diameter would be salvaged, so that the realizable increment would approach the gross increment.

Table 8, based on extensive cutting areas on the Coconino, indicates that the sample plots in tables 7 and 10 have a higher volume but a lower number of trees per acre than the average cut-over stand. The excess in numbers on the larger areas is chiefly in the diameters below 12 inches. This indicates that the extensive areas are probably adding less board-foot volume than the sample plots at the present time but that after 40 or 50 years they may yield more than the sample plots.

TABLE 8.—*Number of ponderosa pine trees per acre on cut-over areas, in different diameter classes, Coconino National Forest*

Diameter class (inches)	Oak Creek unit—5,785 acres; 2,038 board feet per acre; cut 1930–31	Mormon Lake unit—3,990 acres; 2,618 board feet per acre; cut 1927–28	Howard Mountain unit—4,930 acres; 2,136 board feet per acre; cut 1912–17
	Number	*Number*	*Number*
4–11	28.11	[1] 16.40	18.37
12–20	3.18	7.62	5.65
21–29	2.17	3.11	2.46
Over 29	.44	.28	.32
Total	33.90	27.41	26.80

[1] 4–7-inch trees omitted.

Strictly comparable data are not available for New Mexico, Colorado, and the Black Hills. It is known, however, that in general the forests in these sections have more trees per acre and smaller ones and that the volumes left after cutting are less than on the Coconino and Tusayan. Thus, in the Black Hills, measurements on 28 sample acres [19] after cutting show 126 trees per acre in the 4- to 11-inch class,

[19] MANAGEMENT PLAN FOR THE CUSTER WORKING CIRCLE. Unpublished.

14 in the 12- to 20-inch class, and none over 20 inches. The average volume per acre on extensive cut-over areas is 1,569 board feet and the calculated annual increment 81.6 board feet. Thus, the Black Hills National Forest with a lower volume of growing stock yields about the same annual increment as the Coconino and Tusayan Forests. Somewhat lower yields are to be expected in New Mexico and probably in Colorado.

Rate of diameter growth is important not only as an index of volume production but also as an index of merchantability. Although little is known about future market demands, it is probably safe to assume that saw logs of fairly large diameter will always be at a premium. In silvicultural cuttings in the Southwest, immature trees of different diameters increase in diameter at nearly a constant rate (table 9). This is because the larger trees usually have crowns and roots in proportion to their basal area. The older trees (yellow pines), however, grow more slowly in the larger diameters. In the Black Hills, the rate of growth is much slower generally, and the large trees grow less rapidly in diameter than the smaller ones. Thus, trees in the 4- to 11-inch class grow 0.106 inch, and in the 12- to 20-inch class, 0.086 inch per year, as compared with 0.169 and 0.181 inch for blackjack in group-selection and shelter-wood cuttings on the Coconino. The lower rate in the Black Hills is obviously due to the greater density.

TABLE 9.—*Diameter growth of ponderosa pine in relation to age and size of trees, Coconino and Kaibab National Forests* [1]

MEAN ANNUAL DIAMETER GROWTH

Plot	Blackjacks, less than 180 years			Yellow pine, 180 years and more		
	4–11 inches d. b. h.	12–20 inches d. b. h.	21–30 inches d. b. h.	12–20 inches d. b. h.	21–30 inches d. b. h.	31–40 inches d. b. h.
	Inches	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
S1, S2, S3	0.142	0.150	0.146			
S5–I	.194	.202	.171	0.148	0.137	0.129
S5–II	.273	.248	.240	.200	.164	.160
S5–III	.171	.191	.194	.148	.135	.131

TREES MEASURED ON PLOTS

	Number	*Number*	*Number*	*Number*	*Number*	*Number*
S1, S2, S3	392	434	101			
S5–I	1,284	1,133	193	77	187	22
S5–II	619	220	120	27	122	49
S5–III	1,022	899	121	104	305	53

[1] Records for plots S1, S2, and S3 cover a period of 20 years (1909–29); records for plots S5–I, II, and III cover a period of 10 years (1913–23).

If all the trees could be expected to survive it would be a simple matter to calculate yield from rate-of-diameter growth applied to a stand table. This is sometimes done. That such calculations would be greatly in error is indicated by the mortality figures compiled by Krauch (*8*) and given in tables 7 and 10. Table 10 also shows that the rate of mortality is highest in the diameter classes above 30 inches (*7*). As shown in table 11 the causes of mortality vary somewhat for different plots, mistletoe and wind being the

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main factors when measured in numbers; on the basis of volume lightning assumes greater importance than here indicated because of its tendency to strike large trees. Lightning and windfall are the main factors contributing to the high mortality of sample plot S5–II. It has been pointed out by Krauch (7) that lightning strikes about the same number of tall trees per acre regardless of the total number present; thus, the percentage of lightning loss on an area bearing only 2 tall trees per acre is likely to be twice as high as on an area bearing 4 tall trees per acre.

TABLE 10.—*Annual mortality of ponderosa pine by diameter classes in percentage of total number of trees in each class*

Plot [1]	Number of trees per acre and annual loss, by diameter class									
	4–11 inches		12–20 inches		21–30 inches		Over 30 inches		All classes	
	Trees	Loss	Trees	Loss	Trees	Loss	Trees	Loss	Trees	Loss
	Number	*Percent*	*Number*	*Percent*	*Number*	*Percent*	*Number*	*Percent*	*Number*	*Percent*
S3	6.4	0.70	7.7	0.36	3.7	0.45	0.3	1.32	18.1	0.57
S4	5.9	.23	6.8	.23	2.3	.40	.3	.46	15.3	.34
S5–I	10.5	.75	9.0	.29	2.9	.49	.2	1.84	22.6	.63
S5–II	4.7	.60	1.8	.55	1.8	.71	.4	1.46	8.7	1.17
S5–III	10.5	.73	9.2	.29	4.0	.53	.6	1.01	24.3	.64

[1] Area of plots and length of record are as given in table 7.

TABLE 11.—*Mean annual mortality of ponderosa pine by causes*

Cause of death	Plot S3	Plot S4	Plot S5–I	Plot S5–II	Plot S5–III
	Percent	*Percent*	*Percent*	*Percent*	*Percent*
Suppression	0.029	0.016	0.054	0.032	0.018
Mistletoe	.282	.000	.262	.182	.242
Wind	.077	.050	.101	.200	.137
Lightning	.041	.022	.026	.084	.029
Insects	.035	.046	.030	.021	.018
Unclassified	.049	.052	.073	.136	.086
Total	.513	[1] .259	.546	.655	.530
	Number	*Number*	*Number*	*Number*	*Number*
Trees per acre	18.1	15.3	22.6	8.7	24.3
Total live trees on plot	8,248	4,651	3,107	1,273	2,666
Total dead trees on plot	847	241	254	125	212

[1] Includes 0.026 cut in trespass and 0.047 killed by fire.

Until sufficient time has elapsed to permit developing a balanced growing stock and until economic conditions are such as to justify more intensive forestry than is being practiced on the national forests, average net increments higher than those which have been indicated, namely, about 80 board feet, cannot be expected generally. Closer utilization would tend to raise this figure, especially in the Southwest where the present minimum diameter is 12 inches d. b. h. On the other hand, it is not known whether the rate of increment established by the end of the first 20 years after cutting can be maintained to the end of the cutting cycle. An important handicap is the fact that much of the earlier cutting left only 1,500 to 2,000 board feet per acre, whereas a growing stock amounting to at least 3,000 board feet per acre is essential to produce a maximum yield. All

things considered, an average annual increment of 80 board feet per acre during the first cutting cycle is probably a fair estimate. This means that by the time of the second cut the volume will have increased by between 4,000 and 5,000 board feet per acre in the Southwest, where the cutting cycle is set at about 60 years in present management plans, and by somewhat less than 3,000 board feet in the Black Hills, where a 35-year cutting cycle has been adopted. As has been pointed out, these yields might easily be increased by 50 percent or more under really intensive management, which would generally mean shorter cutting cycles and a larger residual growing stock after each cutting.

COSTS AND RETURNS

The market value of a crop to be harvested 50, 100, or 200 years hence is even more a subject for speculation than yields in volume and quality of wood. Economic conditions may change radically, and no one can definitely predict what the demand for wood products will be 50 years hence. That a market will exist for all wood that can be produced and sold at a reasonable cost is scarcely to be doubted; but whether it will be mainly in the form of cellulose or in the form of saw logs, and what price can be obtained for the raw materials, are matters on which opinion differs. Granting that great progress will be made in the development of processes for converting low-grade material into usable products, it is probable that those processes will be applied mainly in utilizing what is now classed as waste. Information now available provides no valid grounds for believing that the growing of small-sized timber will prove more profitable than the growing of saw logs.

Although it is difficult on account of the many uncertainties to present definite figures on costs and returns, it is nevertheless important to recognize the factors for and against the economic success of timber growing in the region under consideration. One of the most adverse factors is the relatively slow rate of tree growth. To an even greater extent here than in forests which mature more quickly, the accumulation of carrying charges over the long period required to grow a timber crop starting with bare land is likely to exceed the amount that can be realized for the crop. A form of forest management based on clear cutting and restocking by either natural or artificial means is not likely to prove financially profitable, except under especially favorable circumstances, and probably on relatively small areas. Private owners may, however, find it advantageous to retain ownership of cut-over land already stocked with young growth, provided such land constitutes a minor portion of a sustained-yield forest property.

Management of forests in these regions by a clear cutting system is just as undesirable for public as for private forests. In the case of public forests, however, there can be little doubt as to the desirability of holding and protecting areas of established young growth and of planting much of the land in need of restocking. Public forests do not have to meet annual charges for taxes. The young stands and lands needing restocking are mostly integral parts of larger management units which contain mature timber. Maintenance of a forest cover is in many instances necessary in order to safeguard the public interest in soil, water, and recreation, as well as for timber production.

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Planting costs from $12 to $20 per acre according to soil and climatic conditions. It is not included in the silvicultural measures recommended in this bulletin because the lands with which we are here concerned are assumed to bear enough seed trees for natural restocking. If supplemental planting should appear necessary in order to obtain full stocking, it should be carefully considered whether the cost is warranted.

Although it is generally desirable, in the long run, to hold expenditures below receipts, this may not be practicable or economically sound where forests are in the early stages of management and development. In such cases current expenditures in excess of receipts may be fully justified in order to insure greater returns in the future. High indirect values in some instances may also warrant expenditures that will not be covered by direct income. The primary costs of forest management will be the annual expenditures for protection and administration, a variable portion of which may be charged against grazing and indirect interests such as water resources, game, and recreation. How large this portion may be should be gaged by the values represented and the benefits obtainable. Planting will play a minor role. Thinnings and improvement cuttings will find a place in silviculture when market conditions are such that the material removed can be sold for enough to pay the cost of removal, or perhaps to a limited extent in connection with emergency work projects.

To maintain a fair balance between current expenditures and receipts calls for a large tract under one management on the sustained-yield plan. Under this plan the timber will be cut from an individual acre only at intervals, but on a large area, such as a national forest or group of national forests, cutting will be going on somewhere all the time and there will be a more or less constant flow of timber receipts from the property as a whole. If over a long period receipts equal or exceed expenditures, the forest is said to be self-supporting or revenue-producing.

When the national forests were created it was predicted that within a few years they would become self-supporting. This prediction has not been realized for the entire national-forest system, partly because most of the timber is still inaccessible to markets, and partly because of heavy expenditures for permanent improvements, such as ranger stations, stock fences, telephone lines, and roads, which should be amortized over a long period. The roads are in many instances built mainly for the benefit of the traveling public, and therefore should not be charged against the cost of forest management. Those forests so situated as to permit exploitation of their timber resources in a degree commensurate with their productive capacity have reached or are rapidly approaching a point where receipts equal expenditures for protection and administration. A notable example is the Harney National Forest in the Black Hills, which during the 5 years prior to 1931 yielded a net revenue, even when the cost of roads was included in expenditures. The Coconino National Forest in Arizona, despite the fact that most of the timber nearest the Santa Fe Railroad was logged off or acquired by private interests in pre-national-forest days, has for many years been self-supporting if the cost of roads is not considered. Enough accessible virgin timber remains in this forest to permit a substantial increase in the rate of cutting during the next

half century, and at the end of this period regrowth will maintain the cut indefinitely. A railroad built from the main line of the Santa Fe 100 miles south into the Sitgreaves National Forest in 1918 has put this forest in the same class with the Coconino. In Colorado the San Juan and Montezuma Forests are more than paying the cost of operation, outside of road construction.

As has been pointed out, there are extensive forest areas which, though bearing good stands of timber, are so situated geographically or topographically that their products cannot be marketed. In some instances the transportation problem will be solved in time, but in others the possibilities are very remote. Obviously such lands should occupy a subordinate place in a timber-growing program, and expenditures for protection and administration should be subject to justification on other grounds than those of timber production.

An estimate has been made of the costs and probable returns on a 450,000-acre tract of ponderosa pine on the Sitgreaves National Forest, assuming that it is to be managed primarily for timber production. This timber is practically all accessible for logging, and the growth is better than the average in the Southwest. Timber operations, cutting about 30,000,000 board feet per year, have been in progress since 1920. The annual costs, covering protection, administration of grazing and timber sales, and construction and maintenance of necessary improvements, are estimated at 9.5 cents per acre. Interest on the investment and taxes are not included, since the land is in Government ownership. It should be noted in this connection, however, that 25 percent of the gross receipts from the national forests is required by law to be paid over to the States for the benefit of roads and schools in the counties in which the forests are situated. This has the effect of reducing the forest income by 25 percent. Assuming a net annual increment of 100 board feet per acre at $2 per M board feet on a sustained-yield basis, the gross return from timber sales would be 20 cents per acre, and about 1 cent additional might be obtained from grazing fees. This would leave a net annual return of 11.5 cents per acre (or 6.25 cents after deducting the 25 percent paid to the State). The increment of ponderosa pine on lands of average productivity on national forests in the Southwest probably will not exceed 80 board feet per acre under present standards of management. This would reduce the net income to 7.5 cents per acre (3.25 cents after the 25-percent deduction).

It has been assumed throughout this bulletin that private forestry as a business will not be practiced to any great extent in this region. A primary factor in this assumption is the slow growth of timber. That this alone is not necessarily a prohibiting factor is indicated by the above figures. Where the land and growing stock represent little or no cash investment and cannot readily be converted into cash, as is the case in some instances, a net return of 11.5 cents an acre or even less is reasonable if it can be realized annually, and if taxes do not take a larger share of the income than that represented by the national-forest contribution to roads and schools. It is believed that under especially favorable conditions with respect to quality of land and timber, size of holding, and accessibility to market, forestry has possibilities as a private enterprise in this region. Excepting the Homestake holdings in the Black Hills, however, very few suitable areas of large extent remain in private ownership. The primary requisites for economic success do exist in the national forests and other Govern-

ment-owned forest lands, and for this reason, along with other advantages in the way of low capital investment and important indirect public benefits, the practice of forestry on public lands is considered economically sound.

SUMMARY

The minimum measures necessary to keep forest land productive, discussed in the first part of this bulletin, aim but little higher than to prevent forest destruction. They are intended to apply to land held by private owners who do not intend to practice forestry as a business enterprise but wish to leave their cut-over lands in such condition that public agencies can acquire them and make them into productive forests without undue expense for reforestation. They include fire protection, involving necessary disposal of logging slash; regulation of cutting so as to leave young trees and a few old trees for seed; prevention of unnecessary logging damage; and prevention of excessive damage to young trees by grazing.

If, however, the owner aims at producing the best timber crops the land will support, the standards are a great deal higher, although possible of attainment in the course of time, and generally practicable for land in public ownership. It is assumed that lands handled temporarily under the first plan will sooner or later be acquired by the State or the Federal Government and placed under the more intensive management provided in the second plan.

Measures necessary to grow full timber crops are fundamentally similar to but more intensive than those outlined under the simpler plan. A wider margin of safety and greater precaution against faulty execution are contemplated. The measures requiring special attention may be summarized as follows:

Management of forests awaiting harvest should aim to bring all of the soil into full production as rapidly as possible. This involves obtaining advance reproduction in all open stands and building up the younger age classes usually deficient in virgin stands.

Cutting regulations should aim, in addition to leaving the needed seed trees, to provide a growing stock of such volume and consisting of such age classes as to permit a series of cuttings at specified intervals on a sustained-yield plan.

Restocking after cutting must be prompt and the young stands should be of such density as to encourage production of high quality as well as maximum volume of timber. Restocking must generally be by natural rather than artificial means because planting is too expensive.

Soil productivity must be maintained. The first step in soil conservation is to encourage absorption of water by maintaining a soil cover. Cutting, logging, and grazing practices should provide adequate safeguards against disturbance of soil cover.

The best development of young stands requires that attention be given to the porcupine, to other rodents, and to insects, as well as to diseases, and especially to mistletoe. The place of thinning and pruning in a silvicultural program will be determined by their influence on costs and returns.

Grazing will probably always be more or less inseparable from forest management in the Southwest. Improved methods of range management, with special reference to numbers of stock, distribution,

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and seasons, will go far toward eliminating damage to seedlings. As an additional safeguard, forest managers should be constantly on the alert for grazing damage. It is of great importance to know that until seedlings are 2 years old they may be completely obliterated by severe browsing, whereas after this age, although retarded in growth, they are rarely killed, except where browsing is repeated year after year.

Watershed protection has long been recognized as a primary function of forest management. Good silviculture in striving to maintain a complete cover of trees, seedlings, and leaf-litter automatically tends to check erosion, decrease surface run-off, and increase the flow from underground sources.

Timber growing cannot be generally recommended in this region as an investment for private capital, but it is regarded as a feasible and necessary public enterprise. From a public viewpoint the cost of administration, protection, and management of forest lands is not as a rule chargeable entirely against the timber crop, but is properly shared by other interests such as grazing, watershed protection, and recreation.

The intensity of silvicultural measures should be governed by the productive capacity and accessibility of the land. As a rule, measures calling for a considerable cash outlay will have to be eliminated or confined to good lands so located that their products can be marketed profitably. The expenditures justified must be determined separately for each forest area considered.

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STRENGTH AND RELATED PROPERTIES OF WOODS GROWN IN THE UNITED STATES

By

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AND

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Forest Service

UNITED STATES DEPARTMENT OF AGRICULTURE, WASHINGTON, D. C.

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STRENGTH AND RELATED PROPERTIES OF WOODS GROWN IN THE UNITED STATES

By L. J. MARKWARDT[1] and T. R. C. WILSON, *senior engineers, Forest Products Laboratory,*[2] *Division of Research, Forest Service*

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[2] Maintained by the U. S. Department of Agriculture at Madison, Wis., in cooperation with the University of Wisconsin.

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PURPOSE AND RELATION TO OTHER PUBLICATIONS

A knowledge of the properties of any material is essential to its proper use. In recognition of this fact the Forest Products Laboratory in 1910 began a comprehensive series of tests to determine the mechanical, and some of the related physical properties of native woods. Several hundred thousand tests have been made yielding data in varying quantity on 164 species. This bulletin presents data from this study, together with related information on factors that affect strength properties.

The tests reported here were made on clear wood, free from defects that affect the strength. Inasmuch as the strength of wooden members in structural and industrial use is affected by numerous variables, such as species of wood, variation in quality of the clear wood and in defects among pieces of the same species, character and distribution of load and duration of stress, temperature and moisture conditions, and size and shape of the piece, it may be asked, "why make tests on clear wood?"

Information for application to such uses may obviously be obtained by testing actual structural members or finished manufactured articles under such conditions as obtain in service and with defects as found in such pieces. Some earlier investigations by the Forest Service included tests of this character. However, the results of such tests accurately represent only the combination of variables existing in each instance, are difficult to interpret with respect to the separate effects of each variable, and cannot be applied to instances in which a different combination exists. Furthermore, the combinations are so numerous that it is impossible to evaluate them all by such tests, consequently, the limited usefulness of the data was soon evident. The plan that has been largely followed by the Forest Service has been to obtain data that are more generally applicable by testing small clear specimens taken from a specific part of the tree and of a standard size and form according to standardized methods and supplementing the resulting basic data on each species by investigations in which the effects of the more important variables are as far as possible separately studied and evaluated. The supplementary investigations have related to the effects on strength induced by such variables as locality of growth, position in tree, rate of growth, knots, cross grain, pitch pockets, moisture content, size and shape of piece, duration of stress, preservative treatment, and kiln drying. These and other supplementary investigations are the basis for the discussion of factors affecting the strength of wood as presented in pages 31 to 74.

Some of the results of the tests on small clear specimens were combined into simplified comparative figures and published in 1930 in United States Department of Agriculture Technical Bulletin 158 (*28*).[3] Because of their popularized form, data in Technical Bulletin 158 are not suitable for such engineering uses as calculating the strength or size of members, but are usable mainly for comparing species.

The information given here, on the other hand, is more technical, and may be used not only (1) for comparing species but also (2) for calculating the strength of wood members, (3) for establishing safe working stresses when used in conjunction with other information including results of tests of structural timbers, and (4) for grouping

[3] Italic numbers in parentheses refer to Literature Cited, p. 74.

species into classes of approximately like properties for various purposes. The present bulletin is based on the same series of tests, but supersedes United States Department of Agriculture Bulletin 556 (*37*), because it covers additional species and additional tests on species previously reported. Another important difference is that the values for air-dry wood as given herein have been adjusted uniformly to a 12-percent moisture content, thus making them directly comparable as presented. In addition to the data from the standard series of tests begun in 1910 there is included herein results of all earlier tests by the Forest Service that were made in such a manner as to afford data of comparable character to that resulting from the standard series.

MEANING AND IMPORTANCE OF STRENGTH

In a broad sense "strength" implies all those properties that fit a material to resist forces. In a more restricted sense, strength is resistance to stress of a single kind, or to the stresses developed in a particular member. Definiteness requires that the name of the specific property be stated; as for instance, strength in shear, strength in compression parallel to grain, or strength as a short column. If the several strength properties had the same relation to each other in all species, a wood that excels in one property would, of course, be higher in all, and misinterpretation of "strength" would be less likely. Actually, however, a species may rank higher in one strength property than in another. Longleaf pine averages higher than white oak in maximum crushing strength parallel to the grain, but lower in hardness. Hence, it cannot be said that longleaf pine is "stronger" or "weaker" than white oak without specifiying the kind of strength. In comparing species for a particular use the kind of strength properties or combination of properties essential to that use must be considered. Thus, from the comparisons just cited, longleaf pine is superior to oak for use as short posts carrying heavy endwise loads, whereas oak excels in resistance to wear and marring.

In most uses the serviceability of wood depends on one or more strength properties. Airplane-wing beams, floor joists, and wheel spokes typify uses in which strength is a major consideration. Other uses often require strength in combination with other characteristics. Telephone poles, railroad ties, and bridge stringers must not only carry loads, but must also resist decay. In addition, many uses not ordinarily associated with strength depend to some degree on strength properties. For example, finish and trim for buildings should be sufficiently hard to avoid marring; window sash must have screw-holding ability to permit secure attachment of hardware, and adequate stiffness to prevent springing when the window is opened and closed. Even matches must have strength to avoid breaking. Information on strength properties is therefore important not only in the design of airplanes, buildings, and bridges, but also as a guide to the selection of wood for a great variety of uses.

The data reported here refer to some of the properties that are important in many uses. Obviously, any such series of mechanical tests does not answer all questions concerning suitability for a given use because the use may involve strength properties that have not been evaluated and because characteristics other than strength (p. 26) are usually also important.

TESTING PROCEDURE

The material for test was identified botanically in the woods and was brought to the Forest Products Laboratory at Madison, Wis., in the green condition in log form. The procedure for selection and care of material, method of preparing test specimens, and method of testing are the result of many years of development in studying wood properties in the United States and embody some features of European practice. Methods of Testing Small Clear Specimens of Timber adopted as standard by the American Society for Testing Materials (*4*), and the American Standards Association is essentially the same as the procedure used. A generally similar procedure is also being followed in a number of other countries. Detailed description of the procedure used, and of the methods of computing the results are presented in the appendix, p. 78.

SCOPE OF TESTS

Many individual pieces of each species were tested in determining the average values of strength properties as presented in table 1. In all over 250,000 tests have been made. Only the average results for each species are, however, presented here. It is difficult to determine how many tests should be made on each species. The larger the number, the nearer may the average values be expected to approach the true average of the species, but also the greater is the cost. A balance must be reached between these desiderata, so that a species usually has been represented by only five trees from any one site or locality. Two or more five-tree units, however, from different localities have been tested for the more important species. The individual tests on a species vary in number from about a hundred to several thousand.

CONSIDERATIONS CONCERNING USE OF TABLE 1

The values given in table 1 are the best available valuations of the true averages. Those for the less important species, being based on fewer tests, are less reliable than those for the common species. In applying the data, too great emphasis should not be placed on small differences in averages. The importance of such differences depends largely on the use to which the wood is put. A discussion of variability and the significance of differences between averages is presented on page 17.

The results obtained in tests of clear wood depend not only on the inherent characteristics of the wood but also on such extrinsic factors as the size and form of specimens, the rate of loading, and other features of testing procedure, and in seasoned material on the moisture content. Care should accordingly be used in comparing the data with that from tests in which a different procedure may have been used and the moisture content of test material should be taken into consideration.

The values in table 1 are primarily for the comparison of species in the form of clear lumber. For comparing structural timbers in which the defects are limited with reference to their effect on strength, allowable working stresses are preferable (*29*, *61*).

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	Impact bending			Compression parallel to grain		Compression perpendicular to grain; stress at proportional limit	Hardness; load required to embed a 0.444-inch ball to ½ its diameter		Shear parallel to grain; maximum shearing strength	Cleavage; load to cause splitting	Tension perpendicular to grain; maximum tensile strength
	Stress at proportional limit	Work to proportional limit	Height of drop causing complete failure (50-pound hammer)	Stress at proportional limit	Maximum crushing strength		End	Side			
	20	21	22	23	24	25	26	27	28	29	30
	Lb. per sq. in.	*In.-lb. per cu. in.*	*Inches*	*Lb. per sq. in.*	*Lb. per sq. in.*	*Lb. per sq. in.*	*Pounds*	*Pounds*	*Lb. per sq. in.*	*Lb. per in. of width*	*Lb. per sq. in.*
Alder,	8,000	2.6	22	2,620	2,960	310	550	440	770	220	390
	11,600	**4.8**	**20**	**4,530**	**5,820**	**540**	**980**	**590**	**1,080**	**270**	**420**
Apple	7,600	3.0	33	1,990	3,000	850	1,040	1,090	1,640	480	900
	15,700	**7.8**	**43**	**3,120**	**6,030**	**1,300**	**2,150**	**1,730**	**1,740**		
Ash, I	11,900	4.9	30	3,530	3,980	880	950	850	1,230	340	540
	16,500	**7.9**	**40**	**5,670**	**7,380**	**1,510**	**1,590**	**1,140**	**1,680**	**410**	**710**
Ash, b			33	1,690	2,300	430	590	520	860	280	490
			35	**4,520**	**5,970**	**940**	**1,150**	**850**	**1,570**	**380**	**700**
Ash, b	11,100	5.0	43	3,580	4,180	990	1,140	1,030	1,540	350	580
	18,400	**9.2**	**42**	**5,460**	**6,980**	**1,760**	**1,720**	**1,290**	**2,030**	**440**	
Ash, g	11,400	5.0	35	3,560	4,200	910	960	870	1,260	350	590
	16,400	**7.6**	**32**	**5,120**	**7,080**	**1,620**	**1,630**	**1,200**	**1,910**	**440**	**700**
Ash, C	8,900	3.0	39	2,760	3,510	650	850	790	1,190	310	590
	13,300	**5.2**	**33**	**4,100**	**6,040**	**1,540**	**1,430**	**1,160**	**1,790**	**410**	**720**
Ash, p	8,800	3.7	31	2,850	3,360	990	880	750	1,210	360	570
	13,600	**6.8**	**24**	**3,950**	**5,690**	**1,800**	**1,430**	**990**	**1,720**	**430**	**770**
Ash, w	13,900	5.9	38	3,190	3,990	810	1,010	960	1,380	330	590
	17,000	**8.2**	**43**	**5,790**	**7,410**	**1,410**	**1,720**	**1,320**	**1,950**	**480**	**940**
Aspen	7,000	2.7	22	1,670	2,140	220	280	300	660	140	230
	9,000	**3.4**	**21**	**3,040**	**4,250**	**460**	**510**	**350**	**850**	**210**	**260**
Aspen	7,400	2.5	18	2,020	2,500	250	400	370	730	190	310
	11,400	**4.7**	**22**	**4,090**	**5,300**	**560**	**620**	**420**	**1,080**	**220**	**390**
Basswo	6,300	2.1	16	1,690	2,220	210	290	250	600	150	280
	9,800	**3.8**	**16**	**3,800**	**4,730**	**450**	**520**	**410**	**990**	**230**	**350**
Beech	11,500	4.4	43	2,550	3,550	670	970	850	1,290	410	720
	16,000	**7.0**	**41**	**4,880**	**7,300**	**1,250**	**1,590**	**1,300**	**2,010**	**490**	**1,010**
Beech	10,100	4.0	106	1,420	2,670	730	900	940	1,160	260	350
	10,300	**4.3**		**3,330**	**5,680**	**2,000**	**1,620**	**1,780**	**2,410**	**680**	
Birch,	9,800	3.7	37	2,050	3,030	430	550	560	920	180	200
	13,700	**4.8**	**40**	**5,290**	**7,450**	**820**	**860**	**830**	**1,400**	**370**	**660**
Birch,	7,400	2.6	59	1,080	1,860	250	430	480			
	10,400	**3.5**	**35**	**2,670**	**4,870**	**920**	**680**	**760**	**1,340**		
Birch,	8,000	2.7	49	1,640	2,360	340	470	560	840	210	380
	12,400	**4.8**	**34**	**3,610**	**5,690**	**740**	**890**	**910**	**1,210**	**540**	
Birch,	10,500	3.2	48	2,680	3,740	580	1,070	970	1,240	300	430
	24,800	**10.6**	**47**	**6,330**	**8,540**	**1,340**	**1,960**	**1,470**	**2,240**	**640**	**950**
Birch,	11,500	4.4	48	2,620	3,380	530	810	780	1,110	270	430
	17,200	**7.3**	**55**	**6,130**	**8,170**	**1,190**	**1,480**	**1,260**	**1,880**	**520**	**920**
Black	15,900	6.8	42	3,760	4,940	1,870	1,570	1,700	1,370	280	660
					8,340	**2,360**					
Bucke	6,500	2.1	18	1,680	2,050	210	360	290	660	180	320
	10,000	**4.3**	**16**	**3,010**	**4,170**	**440**	**470**	**350**	**960**	**240**	**520**
Bustic				3,750	5,330	1,700					
	18,400	**6.6**	**26**	**4,950**	**9,540**						
Butte	7,300	2.5	24	2,020	2,420	270	410	390	760	220	430
	11,200	**4.6**	**24**	**4,200**	**5,110**	**570**	**570**	**490**	**1,170**	**220**	**440**
Butto	14,100	6.8	40	3,050	4,110	1,140	1,080	1,110	1,220	370	470
					7,850	**1,630**					
Casca	8,700	3.6	58	1,890	3,270	670	680	730	1,150	260	510
	10,200	**4.6**	**26**	**3,460**	**6,080**	**1,310**	**1,240**	**1,040**	**1,610**		
Catalp	7,500	3.1	35	1,450	2,360	320	420	410	680	220	430
	11,000	**4.3**	**27**	**2,740**	**4,970**	**570**	**650**	**550**	**1,130**	**300**	**570**
Cherr	10,200	4.1	33	2,940	3,540	440	750	660	1,130	330	570
	13,600	**5.4**	**29**	**5,960**	**7,110**	**850**	**1,470**	**950**	**1,700**	**350**	**560**
Cherr	6,600	2.1	22	1,810	2,170	260	440	390	680	170	300
	10,100	**4.0**	**31**	**3,930**	**4,620**	**520**	**740**	**510**	**1,030**	**230**	**320**
Chesti	7,900	2.8	24	2,080	2,470	380	530	420	800	240	440
	10,700	**4.6**	**19**	**3,780**	**5,320**	**760**	**720**	**540**	**1,080**	**250**	**460**
Chinq	8,800	3.4	31	2,030	3,020	490	730	600	1,010	230	480
	10,900	**4.8**	**30**	**4,150**	**5,540**	**680**	**840**	**730**	**1,260**		
Cotto	7,200	2.3	21	1,740	2,280	240	380	340	680	220	410
	7,300	**2.4**	**20**	**3,490**	**4,910**	**470**	**580**	**430**	**930**	**270**	**580**
Cotto	6,800	2.2	20	1,760	2,160	200	280	250	600	170	270
	9,800	**3.8**	**22**	**3,270**	**4,420**	**370**	**540**	**350**	**1,020**	**220**	**330**
Dogw	7,100	3.5	58		3,640	1,030	1,410	1,410	1,520		
	14,600	**7.5**	**44**		**7,700**	**1,920**	**2,430**	**2,150**	**2,260**		
Dogw	9,800	3.6	56	2,410	3,640	870	1,140	980	1,300	340	740
	10,500	**3.7**	**34**	**4,300**	**7,540**	**1,650**	**1,870**	**1,350**	**1,720**	**410**	**1,040**
Elder,	8,000	2.9	38	2,380	3,040	520	760	720	1,090	320	560
	10,500	**5.1**	**33**	**3,860**	**5,090**	**760**	**860**	**840**			

126695°—35. (Face p. 4.) No. 1.

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	Impact bending			Compression parallel to grain		Compression perpendicular to grain: stress at proportional limit	Hardness; load required to embed a 0.444-inch ball to ½ its diameter		Shear parallel to grain; maximum shearing strength	Cleavage; load to cause splitting	Tension perpendicular to grain; maximum tensile strength
	Stress at proportional limit	Work to proportional limit	Height of drop causing complete failure (50-pound hammer)	Stress at proportional limit	Maximum crushing strength		End	Side			
	20	21	22	23	24	25	26	27	28	29	30
	Lb. per sq. in.	*In.-lb. per cu. in.*	*Inches*	*Lb. per sq. in.*	*Lb. per sq. in.*	*Lb. per sq. in.*	*Pounds*	*Pounds*	*Lb. per sq. in.*	*Lb. per in. of width*	*Lb. per sq. in.*
			38	1,920	2,910	440	680	620	1,000		590
Elm,			**39**	**4,030**	**5,520**	**850**	**1,110**	**830**	**1,510**		**660**
		4.6	54	2,970	3,780	750	980	940	1,270		
Elm, r		**7.9**	**56**	**4,700**	**7,050**	**1,520**	**1,510**	**1,320**	**1,920**		
	9,200	3.4	47	2,790	3,320	510	750	660	1,110	380	640
Elm, s	**15,300**	**7.5**	**45**	**4,760**	**6,360**	**1,010**	**1,120**	**860**	**1,630**	**340**	**530**
					2,630	650	620	580			
Fig, gd					**4,410**						
	9,800	4.0	30	2,490	3,040	600	790	640	1,100	330	570
Gum,	**14,500**	**7.1**	**22**	**3,470**	**5,520**	**1,150**	**1,240**	**810**	**1,340**	**340**	**500**
	14,200	4.7	40	4,840	5,250	1,020	1,310	1,340	1,550	360	640
Gum,	**20,500**	**8.8**	**41**	**8,190**	**9,940**	**1,720**	**1,640**	**1,540**	**1,840**		
	10,000	3.9	33	2,230	2,840	460	630	520	1,070	330	510
Gum,	**16,800**	**8.5**	**32**	**4,700**	**5,800**	**860**	**950**	**690**	**1,610**	**380**	**800**
	9,000	3.3	30	2,690	3,370	590	800	710	1,190	340	600
Gum,	**12,500**	**5.8**	**23**	**4,280**	**5,920**	**1,070**	**1,200**	**880**	**1,590**	**360**	**700**
	5,000	2.3	13	930	1,510	290	290	230	590	170	380
Gumb	**6,300**	**2.3**	**9**	**1,720**	**3,080**	**560**	**370**	**270**	**800**	**200**	**360**
	7,900	3.1	48	2,070	2,650	490	760	700	1,070	350	630
Hackb	**13,700**	**7.0**	**43**	**3,710**	**5,440**	**1,100**	**1,110**	**880**	**1,590**	**330**	**580**
					3,110	980	1,220	1,200	1,360		
Haw,					**6,760**	**1,580**	**1,960**	**1,550**			
	14,200	7.0	104	2,740	3,920	1,000			1,190		
Hickor	**22,800**	**13.9**	**88**		**8,000**	**2,220**			**2,110**		
	15,900	8.5	66	4,330	4,570	990			1,240		
Hickor	**23,600**	**12.5**	**66**		**9,040**	**2,070**					
	15,100	6.7	88	3,900	4,480	1,000			1,280		
Hickor	**20,200**	**9.7**	**77**		**8,940**	**2,140**			**1,740**		
	12,800	6.1	54	3,620	3,980	940			1,030		
Hickor					**6,910**	**1,930**					
	16,900	8.8	89	3,950	4,810	1,140			1,370		
Hickor	**25,200**	**13.2**	**74**		**9,190**	**2,450**			**2,150**		
	14,400	6.4	74	3,430	4,580	1,040			1,520		
Hickor	**19,300**	**9.0**	**67**		**9,210**	**2,170**			**2,430**		
	13,700	6.1	56	3,240	4,660	1,090			1,440		
Hickor			**53**	**5,400**	**8,600**	**1,910**					
	8,900	4.4	51	2,050	2,640	610	860	790	1,130	360	610
Holly	**12,500**	**6.9**	**33**	**3,380**	**5,540**	**1,130**	**1,400**	**1,020**	**1,710**		**680**
	11,800	4.6	47	3,320	4,420	1,420	1,440	1,390	1,660	490	930
Honey	**15,400**	**7.4**	**47**	**5,250**	**7,500**	**2,280**	**1,860**	**1,580**	**2,250**	**430**	**900**
	10,600	3.5	73	2,570	3,570	730	1,160	1,170	1,370	330	450
Hopho	**14,200**	**5.8**	**49**	**5,780**	**7,760**	**1,500**	**2,200**	**1,860**	**1,790**		
	15,200	6.8	50	3,310	4,480	1,600	1,320	1,440	1,750	450	
Inkwo			**28**	**4,520**	**8,430**	**2,530**	**3,120**	**2,220**	**2,260**		
	18,500	7.7	35	5,660	7,570	3,460					
Ironw	**16,500**	**5.2**	**14**	**3,400**	**9,940**	**2,860**					
	8,300	4.1	57	1,980	3,020	800	1,020	1,000	1,270	430	780
Laurel	**10,700**	**5.3**	**31**	**3,520**	**5,640**	**1,400**	**1,540**	**1,270**	**1,860**	**420**	**870**
	10,200	5.2	32		4,310	1,110	1,400	1,300	1,670		
Laurel	**14,300**	**7.5**	**40**		**5,920**	**1,820**	**2,090**	**1,790**			
	18,300	7.9	44	6,120	6,800	1,430	1,640	1,570	1,760	400	770
Locust	**21,100**	**9.8**	**57**	**6,800**	**10,180**	**2,260**	**1,580**	**1,700**	**2,480**	**330**	**640**
	10,200	4.7	40	2,430	3,320	780	1,120	940	1,420	430	770
Madro	**10,400**	**4.3**	**23**	**4,040**	**6,880**	**1,620**	**1,890**	**1,460**	**1,810**	**490**	
	9,300	2.9	30	2,810	3,140	410	600	520	990	260	440
Magn	**14,700**	**5.7**	**35**	**4,840**	**6,310**	**710**	**950**	**700**	**1,340**	**290**	**660**
	8,800	3.2	54	2,160	2,700	570	780	740	1,040	340	610
Magn	**13,600**	**6.4**	**29**	**3,420**	**5,460**	**1,060**	**1,280**	**1,020**	**1,530**	**430**	**740**
	8,600	2.9	23	2,270	2,610	330	570	500	830	260	450
Magn	**13,800**	**5.8**	**27**	**4,180**	**5,360**	**620**	**830**	**620**	**1,150**	**320**	**660**
	20,500	8.2	52	5,200	6,490	2,460	2,010	2,240	1,800		
Mangr			**32**	**6,170**	**10,750**	**3,300**		**2,760**	**2,860**		
	8,500	2.8	23	2,510	3,240	550	760	620	1,110	320	600
Maple			**28**	**4,790**	**5,950**	**930**	**1,330**	**850**	**1,730**	**400**	**540**
	10,200	3.8	48	2,800	3,270	740	940	840	1,130	430	720
Maple	**13,500**	**5.6**	**40**	**4,600**	**6,680**	**1,250**	**1,700**	**1,180**	**1,820**	**420**	**670**
			32	2,360	3,280	500	780	700	1,150	290	
Maple			**32**	**4,650**	**6,540**	**1,240**	**1,430**	**950**	**1,850**	**500**	
	6,800	2.6	29	1,930	2,490	460	670	590	1,050	300	560
Maple	**12,400**	**6.9**	**25**	**4,360**	**5,220**	**910**	**1,140**	**700**	**1,480**	**340**	**500**

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	Impact bending			Compression parallel to grain		Compression perpendicular to grain; stress at proportional limit	Hardness; load required to embed a 0.444-inch ball to ½ its diameter		Shear parallel to grain; maximum shearing strength	Cleavage; load to cause splitting	Tension perpendicular to grain; maximum tensile strength
	Stress at proportional limit	Work to proportional limit	Height of drop causing complete failure (50-pound hammer)	Stress at proportional limit	Maximum crushing strength		End	Side			
	20	21	22	23	24	25	26	27	28	29	30
	Lb. per sq. in.	*In.-lb. per cu. in.*	*Inches*	*Lb. per sq. in.*	*Lb. per sq. in.*	*Lb. per sq. in.*	*Pounds*	*Pounds*	*Lb. per sq. in.*	*Lb. per in. of width*	*Lb. per sq. in.*
	8,700	2.3	36	1,790	2,920	500	500		1,150		
Maple,	**11,400**	**5.2**	**27**		**5,540**	**800**	**960**	**700**	**1,320**		
	12,200	4.8	40	2,850	4,020	800	1,070	970	1,460		
Maple,	**20,600**	**9.3**	**39**	**5,390**	**7,830**	**1,810**	**1,840**	**1,450**	**2,330**		
	18,000	8.7	52	4,950	5,880	2,680	1,670	1,770	1,670	430	1,030
Mastic	**14,100**	**5.1**	**24**	**3,940**	**6,930**	**2,830**	**2,090**	**1,790**	**1,470**	**370**	**710**
	11,400	4.9	40	2,720	3,470	870	1,000	1,060	1,220		
Oak, bl	**14,400**	**6.4**	**41**	**4,750**	**6,520**	**1,150**	**1,380**	**1,210**	**1,910**		
	10,000	4.7	44	2,380	3,290	840	1,160	1,110	1,350	430	800
Oak, bu	**14,600**	**8.0**	**29**	**3,580**	**6,060**	**1,480**	**1,410**	**1,370**	**1,820**	**320**	**680**
	8,200	3.4	30	1,880	2,800	890	910	850	1,140	350	700
Oak, C	**8,800**	**4.0**	**16**	**3,300**	**5,640**	**1,440**	**1,180**	**1,100**	**1,470**	**360**	**770**
	11,200	3.9	47	3,940	4,690	1,480	1,590	1,570	1,700	520	970
Oak, ca	**13,000**	**5.5**	**37**	**6,110**	**9,080**	**2,260**	**2,530**	**2,420**	**2,290**	**640**	
	12,000	4.6	35	2,890	3,520	660	970	890	1,210	380	690
Oak, ch	**18,600**	**7.7**	**40**	**4,420**	**6,830**	**1,040**	**1,250**	**1,130**	**1,490**	**380**	
	10,400	3.4	39	2,650	3,170	710	1,020	1,000	1,180	380	770
Oak, la	**14,700**	**5.6**	**39**	**4,640**	**6,980**	**1,310**	**1,230**	**1,210**	**1,830**	**360**	**790**
	17,200	8.5	57	4,170	5,430	2,520	1,670	1,880	2,210	550	1,040
Oak, li	**21,300**	**11.2**	**33**	**5,120**	**8,900**	**3,510**	**3,150**	**2,680**	**2,660**	**520**	**1,010**
	10,300	4.8	49	2,480	3,570	1,380	1,430	1,390	1,630	450	940
Oak, O	**11,900**	**5.4**	**29**	**3,960**	**6,530**	**2,110**	**1,880**	**1,660**	**2,020**	**380**	**830**
	11,900	4.2	48		3,680	880	1,000	1,070	1,290	470	800
Oak, pi	**12,300**	**3.6**	**45**	**4,620**	**6,820**	**1,260**	**1,600**	**1,510**	**2,080**	**530**	**1,050**
	10,900	4.1	44	2,840	3,480	1,060	1,160	1,130	1,280	410	790
Oak, po	**17,600**	**8.6**	**46**	**3,700**	**6,600**	**1,760**	**1,350**	**1,360**	**1,840**	**430**	**780**
	10,600	3.8	44	2,360	3,440	760	1,060	1,000	1,210	430	750
Oak, re	**17,600**	**8.5**	**43**	**4,580**	**6,760**	**1,250**	**1,580**	**1,290**	**1,780**	**410**	**800**
	8,100	4.3	80	1,330	2,940	1,110	1,210	1,280	1,530	370	750
Oak, R	**14,100**	**5.2**	**23**		**5,200**	**2,070**	**2,030**	**1,440**			
	11,900	4.0	54	2,840	4,090	1,030	1,170	1,200	1,410	420	700
Oak, sc	**16,100**	**6.1**	**53**	**5,550**	**8,330**	**1,380**	**1,650**	**1,400**	**1,890**	**450**	**870**
	9,100	3.1	29	2,220	3,030	680	910	860	930	280	480
Oak, so	**15,300**	**7.3**	**26**	**2,910**	**6,090**	**1,080**	**1,020**	**1,060**	**1,390**	**350**	**510**
	12,300	3.8	54	3,820	4,620	940	1,270	1,240	1,320	460	800
Oak, sw	**23,900**	**12.0**	**49**	**6,350**	**8,740**	**1,540**	**1,570**	**1,480**	**2,000**	**410**	**840**
	10,400	3.2	45	3,000	3,540	710	1,100	1,110	1,260	400	670
Oak, sw	**19,000**	**7.9**	**41**	**4,400**	**7,270**	**1,370**	**1,290**	**1,240**	**1,990**	**350**	**690**
	13,300	4.8	50	3,580	4,360	940	1,200	1,160	1,300	480	860
Oak, sw	**22,300**	**11.2**	**49**	**5,830**	**8,600**	**1,470**	**1,680**	**1,620**	**2,000**	**480**	**830**
	11,600	3.8	39	3,260	3,740	770	1,050	1,010	1,240	450	820
Oak, wh	**18,800**	**8.1**	**44**	**3,960**	**6,770**	**1,260**	**1,400**	**1,190**	**2,020**	**470**	**920**
	10,700	4.2	42	3,090	3,560	830	1,120	1,060	1,250	420	770
Oak, wh	**17,100**	**7.5**	**37**	**4,760**	**7,440**	**1,320**	**1,520**	**1,360**	**2,000**	**450**	**800**
	9,200	2.9	35	2,340	3,000	750	1,020	980	1,180	400	760
Oak, wi	**15,600**	**7.6**	**42**	**4,380**	**7,040**	**1,400**	**1,420**	**1,460**	**1,650**		
	15,500	8.9	120	3,980	5,810	2,260	1,840	2,040			
Osage-o											
	5,000	2.7	15	1,410	1,750	190	330	280	570	110	220
Palmet	**6,200**	**2.9**	**16**	**1,450**	**2,220**	**180**	**300**	**360**	**410**	**80**	**130**
	5,400	1.9	7	1,260	1,810	260	350	240	710	150	310
Paradis	**5,500**	**1.5**	**7**	**2,160**	**3,000**	**400**	**600**	**350**	**620**		**330**
	12,300	5.0	53	3,100	3,990	960	1,270	1,310	1,480	420	680
Pecan (	**17,400**	**8.2**	**44**	**5,180**	**7,850**	**2,130**	**1,930**	**1,820**	**2,080**	**660**	
	12,100	4.5	41	3,160	4,170	1,110	1,240	1,280	1,470	410	770
Persim	**18,400**	**8.6**	**37**	**6,390**	**9,170**	**2,460**	**2,520**	**2,300**	**2,160**	**590**	**1,200**
	16,000	6.8	40	4,260	4,940	1,500	1,730	1,720	1,510	400	850
Pigeon-				**4,640**	**7,020**	**2,920**		**2,030**			
	8,100	3.3	15	1,220	2,160	900	400	300	910	180	350
Poisonv					**4,780**	**800**					
	6,000	2.2	16	1,220	1,690	170	240	230	500	130	160
Poplar,	**8,000**	**2.7**	**14**	**2,920**	**4,020**	**370**	**380**	**300**	**790**	**200**	**350**
	8,600	3.3	18	1,930	2,420	330	390	340	740	220	450
Poplar,	**13,500**	**5.6**	**20**	**3,550**	**5,290**	**580**	**560**	**450**	**1,100**	**280**	**520**
Rhodo(			26		3,470	890	1,000	860	1,240		
			19		**6,420**	**1,440**					
Sassafra	8,500	3.5	37	2,400	2,730	460	610	520	950	300	520
	10,600	**5.2**	**33**	**3,260**	**4,760**	**1,050**	**650**	**630**	**1,240**	**300**	**590**
Service	12,200	4.1	63	3,250	4,080	780	1,250	1,240	1,260	400	730
	21,000	**9.6**	**59**	**6,340**	**8,770**	**1,790**	**2,090**	**1,800**	**1,590**		

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	Impact bending			Compression parallel to grain		Compression perpendicular to grain; stress at proportional limit	Hardness; load required to embed a 0.444-inch ball to ½ its diameter		Shear parallel to grain; maximum shearing strength	Cleavage; load to cause splitting	Tension perpendicular to grain; maximum tensile strength
	Stress at proportional limit	Work to proportional limit	Height of drop causing complete failure (50-pound hammer)	Stress at proportional limit	Maximum crushing strength		End	Side			
	20	21	22	23	24	25	26	27	28	29	30
	Lb. per sq. in.	*In.-lb. per cu. in.*	*Inches*	*Lb. per sq. in.*	*Lb. per sq. in.*	*Lb. per sq. in.*	*Pounds*	*Pounds*	*Lb. per sq. in.*	*Lb. per in. of width*	*Lb. per sq. in.*
Silver	9,100	3.3	27	2,140	2,830	430	550	470	930	280	460
	13,300	**6.0**	**24**	**3,580**	**5,130**	**680**	**880**	**590**	**1,180**	**320**	**480**
Sourv	10,800	4.1	38	2,700	3,250	680	860	730	1,160	400	710
	17,200	**8.6**	**38**	**4,400**	**6,190**	**1,080**	**1,350**	**940**	**1,500**	**380**	**520**
Stopp			54		6,140	2,450			1,820		920
			34		**9,790**	**2,790**		**2,600**	**1,850**		
Sugar	8,200	3.2	33	1,990	2,800	580	840	740	1,050	380	660
	11,600	**5.4**	**36**	**3,970**	**5,620**	**1,240**	**1,280**	**960**	**1,280**	**380**	
Sumac					2,680	480	670	590			
					5,940	**1,010**	**880**	**680**			
Sycar	8,800	3.3	26	2,400	2,920	450	700	610	1,000	330	630
	10,500	**3.9**	**26**	**3,710**	**5,380**	**860**	**920**	**770**	**1,470**	**400**	**720**
Waln	11,900	4.5	37	3,520	4,300	600	960	900	1,220	360	570
	16,400	**8.2**	**34**	**5,780**	**7,580**	**1,250**	**1,050**	**1,010**	**1,370**	**320**	**690**
Waln	9,900	4.5	46		3,020	760					
	11,100	**4.5**	**21**		**6,760**						
Willo	5,100	2.0	36	960	1,520	220	350	360	620	230	430
	7,700	**3.6**	**20**	**2,020**	**3,420**	**480**	**550**	**450**	**1,050**	**290**	**460**
Willo	7,600	2.5	33	1,810	2,340	330	490	500	870	210	360
	11,000	**4.7**	**31**	**3,120**	**4,560**	**630**	**850**	**630**	**1,160**	**290**	**530**
Witc	12,400	6.3	40		3,400	620	1,010	980	1,120		
					6,740	**1,370**	**1,860**	**1,530**			
Ceda	9,100	3.2	27	2,500	3,050	430	540	440	840	170	330
	12,200	**5.0**	**29**	**5,210**	**6,310**	**770**	**790**	**580**	**1,130**	**180**	**360**
Ceda	7,300	2.4	17	2,940	3,150	460	570	390	830	160	280
	9,600	**3.9**	**17**	**4,760**	**5,200**	**730**	**830**	**470**	**880**		**270**
Ceda	9,200	3.0	22	2,770	3,130	350	460	400	830	100	180
	13,500	**5.0**	**28**	**5,890**	**6,470**	**760**	**730**	**560**	**1,080**	**220**	**400**
Ceda	7,000	2.7	35	2,540	3,570	860	760	650	1,010	180	330
	8,500	**4.6**	**22**		**6,020**	**1,140**	**900**	**900**		**260**	
Ceda	10,500	5.4	18	3,910	4,360	910	810	580	1,190	210	400
	10,200	**4.2**	**17**	**5,190**	**6,570**	**1,000**	**1,010**	**610**	**750**		
Ceda	6,900	2.5	17	2,470	2,750	340	430	270	710	140	230
	8,600	**3.2**	**17**	**4,360**	**5,020**	**610**	**660**	**350**	**860**	**130**	**220**
Ceda	5,300	2.0	15	1,490	1,990	290	320	230	620	140	240
	7,100	**2.8**	**12**	**2,630**	**3,960**	**380**	**450**	**320**	**850**	**150**	**240**
Ceda	6,000	2.2	18	1,660	2,390	300	400	290	690	120	180
	7,600	**3.0**	**13**	**2,740**	**4,700**	**500**	**520**	**350**	**800**	**130**	**220**
Cypr	8,800	3.3	25	3,100	3,580	500	440	390	810	180	300
	10,400	**3.9**	**24**	**4,470**	**6,360**	**900**	**660**	**510**	**1,000**	**170**	**270**
Doug	9,800	3.2	24	3,410	3,890	510	510	480	930	160	240
	12,700	**4.5**	**30**	**6,450**	**7,420**	**910**	**760**	**670**	**1,140**	**180**	**300**
Doug	8,700	2.7	22	2,570	3,300	480	510	450	840	190	300
	11,600	**4.4**	**27**	**5,540**	**6,720**	**920**	**710**	**600**	**1,130**	**190**	**340**
Doug	9,100	3.0	20	2,540	3,000	450	450	400	880	160	350
	12,100	**4.8**	**26**	**4,660**	**6,060**	**820**	**740**	**630**	**1,070**	**160**	**330**
Fir, s	5,300	1.6	9	1,690	2,060	310	280	220	610	130	
	7,000	**2.3**	**16**	**3,740**	**4,330**	**600**	**470**	**400**	**1,020**	**140**	
Fir, l	6,900	2.3	16	2,080	2,400	210	290	290	610	130	180
	7,800	**2.6**	**20**	**3,970**	**4,530**	**380**	**510**	**400**	**710**		**180**
Fir, c	5,600	2.0	12	1,630	2,010	190	280	210	600	150	300
	8,200	**2.7**	**13**	**3,820**	**4,110**	**470**	**470**	**290**	**840**	**170**	**280**
Fir, l	8,100	2.6	22	2,640	3,020	340	420	360	760	150	240
	12,000	**4.6**	**28**	**4,420**	**5,430**	**620**	**660**	**490**	**930**	**190**	**240**
Fir, l	8,600	2.9	19	2,420	2,740	340	330	290	750	150	230
	11,200	**3.8**	**23**	**4,960**	**5,550**	**640**	**690**	**410**	**980**	**150**	**220**
Fir, (	8,600	2.8	22		2,830	440	390	380	920	190	340
	12,000	**4.3**	**23**		**5,290**	**850**	**1,090**	**530**	**1,050**	**190**	**350**
Fir, s	7,800	2.2	21	2,380	2,670	290	360	310	670	150	240
	11,400	**4.8**	**24**	**4,660**	**5,550**	**490**	**620**	**430**	**1,050**	**200**	
Fir, v	8,500	2.9	22	2,390	2,710	370	380	330	750	170	290
	10,800	**4.1**	**17**	**3,590**	**5,350**	**600**	**730**	**440**	**930**	**160**	**260**
Hem	7,900	2.9	21	2,600	3,080	440	500	400	850	150	230
	10,700	**4.6**	**21**	**4,020**	**5,410**	**800**	**810**	**500**	**1,060**	**150**	
Hem	9,100	3.5	32	2,540	3,150	470	600	500	910	200	330
	13,300	**5.8**	**32**	**4,620**	**6,840**	**1,030**	**1,170**	**740**	**1,230**	**170**	**320**
Hem	8,100	2.8	22	2,480	2,990	390	520	430	810	190	310
	12,400	**5.4**	**26**	**5,340**	**6,210**	**680**	**940**	**580**	**1,170**	**200**	**310**

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	Impact bending			Compression parallel to grain		Compression perpendicular to grain; stress at proportional limit	Hardness; load required to embed a 0.444-inch ball to ½ its diameter		Shear parallel to grain; maximum shearing strength	Cleavage; load to cause splitting	Tension perpendicular to grain; maximum tensile strength
	tress at portional limit	Work to proportional limit	Height of drop causing complete failure (50-pound hammer)	Stress at proportional limit	Maximum crushing strength		End	Side			
	20	21	22	23	24	25	26	27	28	29	30
	b. per . in.	*In.-lb. per cu. in.*	*Inches*	*Lb. per sq. in.*	*Lb. per sq. in.*	*Lb. per sq. in.*	*Pounds*	*Pounds*	*Lb. per sq. in.*	*Lb. per in. of width*	*Lb. per sq. in.*
J	5,800	3.9	21	2,490	3,730	1,030	960	820	1,280		
	5,600	**2.5**	**12**		**4,120**	**1,700**	**1,290**	**1,160**			
L	9,400	3.7	24	3,250	3,800	560	470	450	920	160	230
	5,100	**7.3**	**32**	**5,950**	**7,490**	**1,080**	**1,110**	**760**	**1,360**	**160**	**310**
P	7,800	3.3	30	2,180	2,580	380	380	370	760	180	310
	4,100	**4.7**	**35**		**5,400**	**820**	**660**	**580**	**1,120**	**200**	**390**
P	7,200	2.6	21	2,050	2,370	350	320	340	690	160	260
	2,500	**5.3**	**27**	**4,240**	**5,530**	**790**	**610**	**500**	**1,210**	**250**	**380**
P	7,100	2.6	18	1,850	2,410	320	300	310	740	170	270
	1,400	**5.2**	**19**		**5,290**	**720**	**510**	**430**	**800**	**260**	**220**
P	8,900	3.0	30	2,550	3,490	480	420	450	850	180	260
	2,100	**4.2**	**30**	**4,820**	**7,080**	**980**	**750**	**690**	**1,370**	**270**	**470**
P	7,200	2.3	20	2,110	2,610	310	320	330	680	150	220
	0,600	**3.8**	**20**	**4,310**	**5,370**	**750**	**530**	**480**	**880**	**180**	**290**
P	0,100	3.2	35	3,430	4,300	590	550	590	1,040	210	330
	5,400	**6.1**	**34**	**6,150**	**8,440**	**1,190**	**920**	**870**	**1,500**	**270**	**470**
P	0,200	3.8	29	2,980	3,540	560	480	490	960	200	320
	4,200	**6.4**	**29**	**4,260**	**6,830**	**1,210**	**730**	**660**	**1,200**	**200**	**360**
P	8,700	2.2	17	2,060	2,490	290	310	310	660	140	240
	2,500	**3.7**	**19**	**3,680**	**4,840**	**550**	**500**	**400**	**860**	**160**	**300**
P	7,500	2.2	28	2,410	3,080	360	360	340	780	160	190
	5,900	**6.8**	**25**	**5,330**	**7,340**	**830**	**670**	**580**	**1,230**	**200**	**490**
P	0,000	3.2	28	1,950	2,950	450	420	470	860	190	280
	2,600	**5.8**	**31**	**3,960**	**5,940**	**1,010**	**700**	**620**	**1,360**	**260**	**480**
P	0,400	3.2	33	2,940	3,660	540	460	510	940	190	280
	3,200	**5.0**	**28**	**6,300**	**7,540**	**1,120**	**780**	**740**	**1,380**	**240**	**360**
P	8,800	2.5	20	2,070	2,400	360	300	310	680	170	290
	9,800	**4.0**	**17**	**4,060**	**5,270**	**740**	**550**	**450**	**1,160**	**220**	**400**
P	0,800	4.6	25	2,670	3,440	560	460	480	1,140		380
	2,400	**5.4**	**19**	**3,900**	**6,920**	**1,030**	**950**	**730**	**1,100**		**300**
P	8,600	2.9	30	2,500	3,430	440	410	440	850	200	320
	3,600	**5.2**	**33**	**5,090**	**7,070**	**1,000**	**750**	**690**	**1,310**	**270**	**470**
P	0,800	3.9	36	3,040	4,340	680	600	630	1,000	230	400
	2,800	**5.8**	**36**	**6,280**	**9,100**	**1,390**	**1,080**	**1,010**	**1,730**	**290**	**570**
P	7,400	2.6	17	2,330	2,530	350	320	310	680	180	270
	0,700	**4.4**	**18**	**4,140**	**4,770**	**590**	**530**	**380**	**1,050**	**190**	**350**
P	7,600	2.6	19	2,430	2,650	290	310	310	640	160	260
	1,900	**4.5**	**23**	**4,480**	**5,620**	**540**	**440**	**370**	**850**	**160**	
P	8,200	4.2	21	1,810	2,590	480	510	600	920		460
	5,500	**3.0**	**12**		**6,400**	**1,520**	**920**	**860**			
R	8,900	3.2	21	3,700	4,200	520	570	410	800	170	260
	9,200	**3.6**	**19**	**4,560**	**6,150**	**860**	**790**	**480**	**940**	**150**	**240**
R	5,900	2.3	14	1,810	2,320	310	390	280	640	160	260
	3,800	**2.7**	**11**	**2,660**	**3,810**	**550**	**590**	**340**	**860**	**160**	**240**
R	7,200	2.5	18	2,840	3,280	350	470	350	730	180	290
	0,100	**3.2**	**16**	**3,750**	**5,240**	**640**	**710**	**400**	**930**	**160**	**280**
S	5,800	1.8	24	1,540	2,570	180	430	370	660	120	100
	3,400	**6.2**	**23**	**4,520**	**5,320**	**650**	**700**	**520**	**1,030**	**160**	
S	5,800	1.9	14	1,680	1,980	290	250	240	590	130	
	0,000	**3.5**	**15**	**3,580**	**4,580**	**640**	**450**	**310**	**1,010**	**200**	
S	7,200	2.3	18	2,380	2,650	340	410	350	760	150	220
	1,900	**4.6**	**25**	**4,610**	**5,890**	**580**	**640**	**490**	**1,080**	**180**	**350**
S	8,400	3.0	24	2,240	2,670	340	430	350	760	150	250
	1,400	**4.2**	**25**	**4,780**	**5,610**	**710**	**760**	**510**	**1,150**	**210**	**370**
S	7,100	2.3	22	2,130	2,570	290	350	320	690	140	220
	0,300	**3.6**	**20**	**3,700**	**5,470**	**570**	**610**	**480**	**1,080**	**200**	**360**
T	7,800	2.7	28	2,930	3,480	480	400	380	860	160	260
	2,500	**5.4**	**23**	**4,780**	**7,160**	**990**	**670**	**590**	**1,280**	**230**	**400**
Y	3,100	6.2	38	3,440	4,650	1,040	1,340	1,150	1,620	250	450
	2,100	**5.5**	**31**	**4,730**	**8,100**	**2,110**	**2,020**	**1,600**	**2,230**	**200**	

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COMMON AND BOTANICAL NAMES OF SPECIES (COLUMN 1)

For convenience, the species listed in table 1 are grouped in two major classifications:

(1) Hardwoods, or trees with broad leaves, usually deciduous; (2) softwoods, or trees with needle or scalelike leaves, usually evergreen and most of them cone-bearing. The two groups are also known as hardwoods and conifers. The terms "hardwoods" and "softwoods" are thus indicative of botanical classification. They are not correlated with the actual hardness or softness of the wood. For example, basswood, poplar, aspen, and cottonwood are classified as hardwoods but are in reality among the softest of native woods, whereas longleaf pine, classed as a softwood, is quite hard.

Avoidance of confusion requires a standard nomenclature for species of wood many of which are known by several common names and to several of which a single common name is often applied. The United States Forest Service has adopted such a nomenclature, designating each species by a single common name, in addition to a botanical name about which confusion rarely exists. The official names are used herein and are those given in Check List of the Forest Trees of the United States, their Names and Ranges, except for a few subsequent changes. Page 92 shows the relation between this nomenclature and commercial lumber names (*46*, *54*).

PLACE OF GROWTH OF MATERIAL TESTED (COLUMN 2)

In the second column are listed the States from which the trees furnishing the test specimens were obtained. The locality of growth has in some instances an influence on the strength of timber (p. 43). That this influence is, however, frequently overestimated is indicated by the fact that fully as great differences have been found between stands of different character grown in the same section of the country as between stands grown in widely separated regions within the normal range of growth. For this reason it is considered better to average together the test data on material from the various localities. However, there is a distinct difference in the properties of Douglas fir from the more arid Rocky Mountain region and those of the Douglas fir from the Pacific Northwest. Further, Douglas fir from the so-called "Inland Empire"[4] region is found to be intermediate in its characteristics between that from the arid Rocky Mountain region and that from the Pacific Northwest. For these reasons separate averages are given for Douglas fir from the Pacific coast, intermediate type, and the Rocky Mountain regions.

MOISTURE CONDITION (COLUMN 3)

Both green and dry material were tested. The resulting data are entered in lines designated "green" and "dry", respectively, in column 3.

Values in the first of each pair of lines beginning with column 3 of table 1 are from tests on green material. Although the moisture content varies among the different species, all tests on green wood were made at approximately the moisture content of the living tree,

[4] Northwestern Montana, Idaho north of the Salmon River, Washington east of the Cascade Mountains, and the northeastern tip of Oregon.

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which is above the limit [5] below which differences in moisture content affect the strength properties.

The strength of dry or partially dry wood depends greatly on the particular stage of dryness and on the distribution of the moisture. Values pertaining to a uniformly distributed moisture content of 12 percent are listed in the second of each pair of lines beginning with column 3. These values were obtained by adjusting values obtained from tests made at various moisture contents. The moisture basis adopted (12 percent) represents an average air-dry condition attained without artificial heat by thoroughly seasoned wood over a considerable portion of the United States, including the Lake States region.

Table 1 shows that in most strength properties the dry material in the form of small, clear specimens excels the green. In large timbers, however, the increased strength of the wood fibers is usually offset by checks and other defects resulting from drying, so that as large increases in strength values as in small specimens cannot be expected.

Except where data on dry material are specifically required, or where significant differences in increase with seasoning is involved, the data on green material are preferable for comparing species, because they are based on a larger number of tests.

NUMBER OF TREES TESTED (COLUMN 4)

The number of trees from which specimens were obtained is stated in the fourth column of table 1. The average values for the more important species represent groups of trees from different localities. Five trees of a species were selected, as a rule, from a single locality.

NUMBER OF RINGS PER INCH (COLUMN 5)

The number of rings per inch measures the rate of growth in diameter or radius of the trees from which the test specimens were cut. Rings per inch were counted along a radial line on the end section of each specimen. One ring, consisting of a band of spring wood and a band of summer wood, is formed during each year. Few rings per inch indicate fast growth, and conversely.

Rate of growth of many species is quite variable, and the values listed are to be regarded mainly as averages of the material tested. Rate of growth does not have a definite relation to strength in the sense of strength being proportional, either directly in inversely, to the rate of growth (p. 44).

SUMMER WOOD (COLUMN 6)

Column 6 shows the proportion of summer wood in the material tested, as measured along a representative radial line. Summer wood is usually much denser than spring wood [6] of the same species so that within a species the proportion of summer wood is indicative

[5] Green wood contains "absorbed", or "imbibed", water within the cell walls and "free" water in the cell cavities. The free water from the cell cavities is the first to be evaporated in drying. The fiber-saturation point is that point at which no water exists in the cell cavities of the timber but at which the cell walls are still saturated with moisture. The fiber-saturation point varies with the species (*15*). The ordinary proportion of moisture—based on the weight of the dry wood—at the fiber-saturation point is about 30 percent. Most strength properties of wood begin to increase, and shrinkage begins to occur, when the fiber-saturation point is reached in seasoning.

[6] Numerous determinations have shown that in the southern pines specific gravity of the summer wood is usually from 2 to 3 times as great as that of the spring wood.

of the specific gravity, and hence, of strength. It is difficult to measure the proportion of summer wood accurately and when the change from spring wood to summer wood is not marked or the contrast between them is not sharp, as in many species, the difficulty is even greater. For this reason the proportion of summer wood is given for only part of the species tested.

Summer wood is unusually well differentiated from spring wood in the southern yellow pines and Douglas fir. Some of the structural grading rules for these species involve, among other features, the selection of pieces showing one-third or more summer wood, such material being awarded as a premium higher working stresses (*54*, *61*).

MOISTURE CONTENT (COLUMN 7)

Moisture content is the weight of water contained in the wood, expressed as a percentage of the weight of the oven-dry wood. Since it is thus expressed it is useful to remember that with a given moisture content in percent a block of wood of a given size contains more weight or volume of water if the wood is heavy than if it is light. Moisture content is commonly determined by weighing a sample and then drying it at 212° F. (100° C.) until the weight becomes constant. The loss of weight divided by the weight of the oven-dry wood is the proportion of moisture in the piece. "Moisture" as thus determined is subject to some inaccuracy, because the loss in weight includes that of any substances other than moisture that evaporate at 100° C. Also some constituents other than actual wood substance are not evaporated. Errors from these sources are not sufficient to affect the practical application of the data given in column 7.

The moisture content listed in table 1 for green material is the average for specimens taken from the pith to the circumference of the log. Hence it represents a combination of the moisture as found in the heartwood and in the sapwood, although not in proportion to the amount of wood represented by each. In each instance 12 percent is entered as the moisture content of "dry" material, because the data have all been adjusted to this basis.

As shown by table 1, the average moisture content of the green wood varies widely among species. Also moisture content often differs between heartwood and sapwood of the same species and in some instances varies with height in the tree. Many coniferous species have a large proportion of moisture in the sapwood and much less in the heartwood. Most hardwoods on the other hand show much more nearly the same moisture content in heartwood and sapwood (p. 29). Extreme limits observed in the moisture content of green wood range from as low as 30 to 40 percent in the heartwood of such species as black locust, white ash, Douglas fir, southern pines, and various cedars to about 200 percent in the sapwood of some coniferous species. In the heartwood of some species the moisture content is high at the base of the tree and becomes less toward the top. For example, in green redwood trees examined at the Forest Products Laboratory, the heartwood decreased in average moisture content from 160 percent at stump height to 60 percent at heights above 100 feet. In this instance the sapwood increased slightly in percentage moisture with height in tree.

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SPECIFIC GRAVITY (COLUMNS 8 AND 9)

Specific gravity is the relation of the weight of a substance to that of an equal volume of water.

The volume occupied by a specified weignt of wood substance changes with the shrinking and swelling caused by changes in moisture content. In table 1, three values of specific gravity are given for each species. They correspond to volumes when green, at 12-percent moisture, and oven-dry, and each is based on the weight of the wood when oven-dry. The number of pounds of wood (exclusive of moisture) in a cubic foot at either of the three moisture conditions may be found by multiplying the specific gravity figure by 62.4. To get the weight per cubic foot of the wood plus that of the associated water, multiply by the factor:

$$1+\frac{\text{percentage moisture content}}{100}$$

Additional data on the specific gravity of a number of species are presented on page 30. For some species these data are more extensive than those of table 1.

SPECIFIC GRAVITY BASED ON VOLUME WHEN GREEN (COLUMN 8)

Values of specific gravity, based on weight when oven-dry and volume when green, are determined from weights and measurements of specimens tested when green. The weight when oven-dry is computed by dividing the weight when green by 1 plus the proportion of moisture, as found from a moisture determination on the same specimen.

The specific-gravity values based on volume when green, as listed in column 8, are averages of determinations made on each green test specimen. The number of determinations is much larger in most instances than those of specific gravity based on volume when air-dry or when oven-dry.

SPECIFIC GRAVITY BASED ON VOLUME WHEN AIR-DRY (COLUMN 8)

Specific gravity based on volume when air-dry is found in the same manner as that based on volume when green, except that the volume measurements are made on air-dry material. The values for air-dry wood listed in column 8 are adjusted to a volume basis corresponding to 12-percent moisture content.

SPECIFIC GRAVITY BASED ON VOLUME WHEN OVEN-DRY (COLUMN 9)

In determining the specific gravity based on volume when oven-dry, the volume as well as the weight is taken after the specimens are oven-dried to practically constant weight at 100° C.

Specific gravity, as listed in column 9, and shrinkage in volume, as listed in column 11, were determined on the same specimens of which there were usually 4 to 6 from a tree.

The difference between specific gravity based on volume when green and that on volume when air-dry or oven-dry, is due to shrinkage, and either specific gravity may be determined from the other if the corresponding shrinkage in volume is known. For example, specific gravity based on weight and volume when oven-dry equals specific

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gravity based on weight when oven-dry and volume when green divided by

$$\left(1-\frac{\text{percent volumetric shrinkage}}{100}\right)$$

As the determinations of specific gravity, based on volume when oven-dry, and of volumetric shrinkage were made on only a few specimens from each bolt, they are not related to specific gravity based on weight when oven-dry and volume when green in exact accordance with this equation.

WEIGHT PER CUBIC FOOT (COLUMN 10)

Changes in moisture content affect the weight of a piece of wood. When the moisture content is below the value at the fiber-saturation point (p. 48), changes in the moisture content also affect the volume of the piece. Consequently, in order to be specific in stating weight per cubic foot, various degrees of dryness must be recognized.

Green or freshly cut wood, contains, as shown in column 7, a considerable proportion of water. After being dried by exposure to the air until the weight is practically constant, wood is said to be "air-dry." If dried in an oven at 212° F. (100° C.) until all moisture is driven off, wood is "oven-dry."

The weights per cubic foot presented in table 1 are based on weights and volumes of small, clear specimens taken usually from the top 4 feet of 16-foot butt logs of typical trees. Because the wood from such portions is often heavier than that from higher in the tree, material thus selected averages slightly heavier than the wood in ordinary timbers, poles, posts, or railway ties.

WEIGHT PER CUBIC FOOT WHEN GREEN

The value for green wood as given in column 10 includes the moisture in the wood as received at the laboratory, and because protection from seasoning was afforded during transit and pending test, it represents closely the weight of the wood as it comes from the living tree. The weight when green is based on the average of heartwood and sapwood pieces as represented by test specimens taken from pith to circumference. In those species which have a higher moisture content in the sapwood, variations in the proportion of sapwood are accompanied by comparatively large variations in weight per cubic foot of green material.

The weights per cubic foot in column 10 correspond to the average moisture-content values listed in column 7. When in specific instances there are large differences in moisture content between heartwood and sapwood and the proportion of sapwood in logs or other products is known, better estimates of the weight per cubic foot when green may be obtained by correcting the value given in column 7 to a suitable moisture content. For example, the weight and moisture content of ponderosa pine are given in table 1 as 45 pounds per cubic foot and 91 percent, respectively. The average moisture content of ponderosa pine logs having 75 percent sapwood by volume is computed on page 30 as 121 percent. The estimated weight of such logs is then

$$45\left(\frac{100+121}{100+91}\right)=51\tfrac{3}{4} \text{ pounds per cubic foot.}$$

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WEIGHT PER CUBIC FOOT WHEN AIR-DRY

Weight per cubic foot depends upon the amount of moisture in the wood which in turn depends on the species, the size and form of the pieces, the length of the seasoning period, and on the rapidity of seasoning as governed by the climate. The average air-dry condition reached in the northern Central States by wood that is sheltered from rain and snow and not artificially heated, is a moisture content of about 12 percent. The values for dry wood in column 10 apply to this moisture content. The moisture content of thoroughly air-dry wood may be 3 to 5 percent higher in humid regions, and in very dry climates, as much lower. It also varies slightly from day to day because of changes in temperature and atmospheric humidity. Large timbers will have a slightly higher average moisture content when thoroughly air-dry than small pieces. Species vary in the rate at which they give off moisture in drying, and also in the rate at which they take up moisture during periods of wet or damp weather.

Changes of several percent in the moisture content of dry wood cause only small changes in the weight per cubic foot, because of two actions which tend to counteract one another. The weight decreases as drying takes place because of the loss of moisture. At the same time shrinkage reduces the volume. Conversely, both weight and volume increase as moisture is absorbed.

Weight per cubic foot at a moisture content near 12 percent may be estimated from that at 12 percent by assuming that one-half percent increase or decrease in weight accompanies an increase or decrease of 1 percent in moisture content. Thus, raising the moisture content from 12 to 14 percent increases the weight per cubic foot about 1 percent and in drying from 12- down to 8-percent moisture content the weight per cubic foot is reduced about 2 percent.

SHRINKAGE (COLUMNS 11, 12, AND 13)

Shrinkage across the grain (in width and thickness) results when wood loses some of the absorbed moisture (pp. 6, 48). Conversely, swelling occurs when dry or partially dry wood is soaked or when it takes moisture from the air or other source. Shrinkage and swelling in the direction of the grain (length) of normal wood is only a small fraction of 1 percent and is too small to be of practical importance in most uses of wood.[7] All shrinkages are expressed as percentages of the original or green dimensions.

Column 11 lists for the various species the shrinkage in volume from the green to the oven-dry condition. The values are averages from actual volume determinations on small specimens.

In columns 12 and 13 are average values of the measured radial and tangential shrinkages in drying standard specimens from the green to the oven-dry condition. Radial shrinkage is that across the annual growth rings as in the width of a quarter-sawed board. Tangential shrinkage is that approximately parallel to the annual-growth rings as in the width of a flat-sawed board.

The shrinkage of any piece of wood depends on numerous factors, some of which have not been thoroughly studied. In all species listed in table 1 the radial shrinkage is less than the tangential. Hence,

[7] Appreciable longitudinal shrinkage is associated with "compression wood", and other abnormal wood structure (p. 72).

quarter-sawed (edge-grained) boards shrink less in width but more in thickness than flat-sawed boards. The smaller the ratio of radial to tangential shrinkage for a species, the greater is the advantage to be gained through minimizing shrinkage in width by using quarter-sawed wood. Also, the less the difference between radial and tangential shrinkage, the less ordinarily is the tendency of the wood to check in drying and to cup when its moisture content changes.

Air-dry wood takes on or gives off moisture with each change in weather or heating conditions. The fact that time is required for these moisture changes, causes a lag between atmospheric changes and their full effect on the moisture condition of the wood. The lag is greater in some species than in others, greater in heartwood than in sapwood, and is much less in small than in large pieces. It is increased by protective coatings such as paint, enamel, or varnish. Some species whose shrinkage from the green to the oven-dry condition is large cause less inconvenience in use than woods with lower total shrinkage, because their moisture content does not respond to atmospheric changes so closely. The shrinkage figures given do not take into account the readiness with which the species take on and give off moisture, and therefore should be considered as the relative shrinkage between woods after long exposure to fairly uniform atmospheric conditions or with the same change in moisture content.

The values listed in columns 11, 12, and 13 are shrinkages from the green to the oven-dry condition and thus are much greater than ordinarily occur in the seasoning of wood or with changes in moisture content subsequent to seasoning. About half the listed value represents the shrinkage from green to the average air-dry condition of 12 to 15 percent moisture. A change in moisture content of dry material by 1 percent may be expected to produce a percentage shrinkage or swelling of about one twenty-fifth of the value listed in columns 11, 12, or 13.

MECHANICAL PROPERTIES (COLUMNS 14 TO 30)

Columns 14 to 30 inclusive list the average values obtained from tests made according to the standardized procedure (pp. 4, 78). For convenience and ease of reference, each of the column headings is discussed independently in the order in which it appears in the table. The reliability of the averages and the significance of differences between species is discussed in a later section on variability. Appreciation of the significance of the values and of how they should be modified to apply to conditions of use differing from those under which the tests were made will be enhanced by study of later discussions, particularly those on form factors and effect of duration of stress. Modifications to make them applicable to material affected by various types of defects are indicated by the discussion of factors affecting strength.

STRESS AT PROPORTIONAL LIMIT, STATIC BENDING (COLUMN 14)

The proportional limit in any test is the limit of proportionality between load (or stress) and deformation (or strain). When load is increased by a given percentage without passing this limit, deformation increases by the same percentage. With an increase in load beyond the proportional-limit value, deformation increases by a

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greater percentage than the load. Both these facts are illustrated by the load-deflection graph shown on page 80.

In accordance with current practice (*3*) in the field of testing materials this bulletin uses "proportional limit", instead of "elastic limit", as used in previous Forest Service publications, to designate the limit of proportionality between stress and strain or between load and deformation.

The determination of the proportional limit in any test is subject to uncertainty because it is somewhat dependent on the increments of load and deflection used in testing and on personal judgment in locating the point of departure from the straight-line relation in such a diagram as shown on page 80. Values of load and deformation at proportional limit for wooden members depend on the rate at which the load is increased and on the length of time it acts on the member. This is illustrated by the fact that stress and deformation at proportional limit are much greater in impact bending, in which the specimen is subjected to instantaneous shocks, than in static bending in which the load increases at a moderate rate.

Because a piece stressed within the proportional limit recovers from its deformation on removal of the load and release of the piece from stress, the proportional limit is sometimes called the elastic limit.

Tests have demonstrated that loads in bending or in compression parallel to grain that exceed the proportional-limit values as found from tests made at the standard speeds (*4*) will ultimately cause failure if they continue to act on a wooden member. Thus, these proportional-limit values of stress are upper limits to the stresses that can be used in the design of permanent structures. In determining safe working stresses, factors of safety must be applied to average values of stress at proportional limit in order to allow for variations below the average and to provide for the contingency that the member will be loaded more heavily than was assumed in its design. The effects of duration and repetition of stress are discussed on page 59.

Stress at proportional limit in static bending (column 14) is the stress that exists in the top and bottom fibers of a beam at the proportional limit load. It is in general applicable to clear beams of rectangular cross section, although a slight adjustment is necessary to adapt values from the standard 2- by 2-inch specimen to pieces of other sizes. In estimating the strength of beams of special forms, such as I, circular, box, or diamond-shaped cross sections, on the basis of the data derived from square specimens as presented herein, the effect of the shape and proportions of the section (p. 63) must be considered.

MODULUS OF RUPTURE, STATIC BENDING (COLUMN 15)

Modulus of rupture is the computed stress in the top and bottom fibers of a beam at the maximum load and is a measure of the ability of a beam to support a slowly applied load for a short time. The formula by which it is computed is based on assumptions that are valid only to the proportional limit, hence modulus of rupture is not a true stress. It is, however, a widely accepted term and values for various species are quite comparable.

Since the modulus of rupture is based on the maximum load, which is directly determinable, it is less influenced by personal and other factors than proportional limit values.

The modulus-of-rupture values are used to compare the bending strengths of different species, and in conjunction with the results of tests on timbers containing defects to determine safe working stresses for structural timbers.

Like stress at proportional limit, modulus of rupture as found from the standard 2- by 2-inch specimens requires some modification to adapt it to square or rectangular beams of other sizes or to make it applicable to beams of I, circular, box, or diamond-shaped cross section (p. 63).

MODULUS OF ELASTICITY, STATIC BENDING (COLUMN 16)

Modulus of elasticity is a measure of the stiffness or rigidity of a material. The deflection of a beam under load varies inversely as the modulus of elasticity; that is, the higher the modulus the less the deflection. Modulus of elasticity is useful for computing the deflections of joists, beams, and stringers under loads that do not cause stress beyond the proportional limit. It is also used in computing the load that can be carried by a long column, because for such columns the load depends on the stiffness, and not on the crushing strength of the wood parallel to the grain.

Some of the deflection that occurs in the bending of a wooden beam is due to shear distortion, the amount varying with the proportions of the piece and the placement of the load. About one-tenth of the deformation measured in tests of the standard bending specimen is due to shearing distortion. The true moduli of elasticity are consequently about 10 percent higher than the values in column 16.

WORK TO PROPORTIONAL LIMIT, STATIC BENDING (COLUMN 17)

Work to proportional limit in static bending, as the name implies, is a measure of the energy that the beam absorbs in being stressed to the proportional limit. Since work is the product of average force times the distance moved, work to proportional limit involves both the load and the deflection at the proportional limit.

Values of work to proportional limit may be used to compare the ability of different species to withstand a combination of high load and high deflection without appreciable injury. Hence, they measure the toughness of a piece to the elastic limit. It is a comparative property only and cannot be used directly like modulus of rupture in strength calculations.

WORK TO MAXIMUM LOAD, STATIC BENDING (COLUMN 18)

Work to maximum load in static bending represents the capacity of the timber to absorb shocks that cause stress beyond the proportional limit and are great enough to cause some permanent deformation and more or less injury to the timber. It is a measure of the combined strength and toughness of a material under bending stresses. Superiority in this quality makes hickory better than ash, and oak better than longleaf pine for such uses as handles and vehicle parts subjected to shock. Work to maximum load is closely related to height of drop in impact bending as a measure of shock resistance.

Work-to-maximum-load values cannot be used directly in design, but, like many others, their usefulness is limited to comparisons.

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TOTAL WORK, STATIC BENDING (COLUMN 19)

Total work in static bending is a measure of the toughness under bending stresses that cause complete failure. Like work to maximum load, it is a measure of that quality which makes hickory a superior wood for handles, and other uses involving shock resistance. It is also indicative of the same quality as is measured by height of drop in impact bending.

STRESS AT PROPORTIONAL LIMIT, IMPACT BENDING (COLUMN 20)

The stress at proportional limit is the computed stress in the top and bottom fibers of the beam at the proportional limit (pp. 11, 84). The stress at proportional limit averages approximately twice as great in impact as in static bending. It is mainly of use in comparing species with respect to their elastic behavior under impact loads. Stress at proportional limit is the only stress computed from the standard-impact-bending test.

It is impossible from the measurements made in this test to find the maximum force between the hammer and the specimen or to compute a maximum stress value analogous to modulus of rupture in static bending. That such a value would, if determined, be considerably higher than modulus of rupture is demonstrated by the fact that stress at proportional limit in impact averages somewhat higher than modulus of rupture. In a few tests in which specimens were broken by a single impact and the maximum force acting on the specimen found from records of the deceleration of the hammer, the computed maximum stress was approximately 75 percent higher than modulus of rupture of similar specimens tested in static bending (*58*).

WORK TO PROPORTIONAL LIMIT, IMPACT BENDING (COLUMN 21)

The work to proportional limit in impact bending is a measure of the energy that the beam absorbs in being stressed to the proportional limit. It involves both the deflection and the stress at proportional limit. Work to proportional limit is used to compare the ability of a timber to absorb shock and recover promptly without injury. It represents a quality important in such products as tool handles or tennis rackets. The values apply only to the resistance to falling bodies or like conditions in which the stress is applied and removed in a fraction of a second.

HEIGHT OF DROP OF HAMMER, IMPACT BENDING (COLUMN 22)

The height of drop of the hammer in impact bending is the height from which the 50-pound hammer is finally dropped to cause complete failure of the standard test specimen. It is a comparative figure expressing the ability of wood to absorb shock that causes stresses beyond the proportional limit. It represents a quality important in such articles as handles, and picker sticks, which are stressed in service beyond the proportional limit. Wood requiring a large height of drop to produce failure usually exhibits a splintering fracture when broken, whereas a small height of drop is associated with a brittle fracture.

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STRESS AT PROPORTIONAL LIMIT, COMPRESSION PARALLEL TO GRAIN (COLUMN 23)

Stress at proportional limit is the greatest stress at which the compressive load remains proportional to the shortening of the specimen (pp. 11, 86).

The stress at proportional limit is applicable to clear compression members for which the ratio of length to least dimension does not exceed 11 to 1. It is the limiting stress in compression parallel to grain which should not be exceeded in determining safe loads. The stress at proportional limit in compression parallel to grain is taken into account in arriving at safe working stresses for short columns and other compression members, determining design values for bolted joints and the like. The stress at proportional limit averages about 80 percent of the maximum crushing strength for coniferous woods, and 75 percent for hardwoods.

MAXIMUM CRUSHING STRENGTH, COMPRESSION PARALLEL TO GRAIN (COLUMN 24)

Maximum crushing strength is the maximum ability of a short piece to sustain a slowly applied end load over a short period. It is applicable to clear compression members whose ratio of length to least dimension does not exceed 11. This property is important in estimating endwise crushing strength of wood, and in developing safe working stresses for structural timbers, design of bolted joints, and the like.

Maximum crushing strength is one of the simplest properties to determine. It is usually less adversely affected by various treatments or processes applied to wood than other strength properties, and hence should not be regarded as representative of other strength properties in appraising the effect of such treatments.

STRESS AT PROPORTIONAL LIMIT, COMPRESSION PERPENDICULAR TO GRAIN (COLUMN 25)

Stress at proportional limit is the maximum across-the-grain stress of a few minutes duration that can be applied without injury through a plate 2 inches wide and covering but a portion of the timber surface. It is useful in deriving safe working stresses in compression perpendicular to grain, for computing the bearing area for beams, stringers, and joists, and in comparing species for railroad ties and other uses in which this property is important.

In compression perpendicular to grain, particularly if the load is applied to only part of the surface area as in this test, wood does not exhibit a true ultimate or maximum strength as in compression parallel to grain and static bending; but the load continues to increase until the block is badly crushed and flattened out. Hence, no ultimate or maximum strength value is obtained.

In the standard test procedure, the specimen is placed with the direction of the annual growth rings parallel to the direction of the load except when this is impossible, such as with specimens from near the pith of the tree. Thus the load is applied to the radial face, but it should be pointed out that the fiber stress at proportional limit in compression perpendicular to grain like other across-the-grain properties of wood are very appreciably affected by ring placement.

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Although there appears to be no consistent difference in fiber stress at proportional limit when the rings are parallel and perpendicular respectively to the direction of the applied load, appreciably lower values obtain when the rings are at an angle of 45°. This fact is of practical importance in timber design and use.

The fiber stress at proportional limit in compression perpendicular to grain depends also on the size of plate with respect to the length of the test specimen. With the surface of the specimen but partly covered, there is a component of tension parallel to grain at the edge of the plate, in addition to the compressive stress proper. Values of proportional limit lower than those obtained with the standard test are found when the plate covers the entire surface of the test specimen, and higher values result when the width of plate is decreased. The method of test employing a plate covering but part of the surface is somewhat analogous to the bearing conditions in service where a joist or beam rests on its supports.

HARDNESS (COLUMNS 26 AND 27)

Hardness is the load required to embed a 0.444-inch ball to one-half its diameter in the wood. It represents a property important in wood subjected to wear and marring, such as flooring, furniture, railroad ties, and paving blocks. The hardness test provides data for comparing different pieces or different species of wood, but the results cannot be used for calculating the size of members, as can such properties as modulus of rupture.

Hardness tests are made on end, radial, and tangential surfaces. End hardness values are given in column 26. There is no significant difference between radial and tangential hardness, and they are averaged together as "side hardness" in column 27.

In determining side hardness the principal stress is perpendicular to the grain, but because of the depth of penetration of the ball, a considerable component of end-grain hardness is introduced in the load. Likewise the end-hardness values reflect a component of side-grain hardness. Although end hardness is usually higher than side hardness, it is evident that the two are closely related.

Although hardness is the best available index of the ability of wood to resist wear, it is not so good a criterion of suitability as would be actual comparisons from some kind of abrasion tests that would more nearly simulate service conditions. However, no abrasion test for wood has yet been standardized and systematic results are not available.

MAXIMUM SHEARING STRENGTH, SHEAR PARALLEL TO GRAIN (COLUMN 28)

Maximum shearing strength is the average stress required to shear off from the test specimen a projecting lip having a length in the direction of the grain of 2 inches. Shearing strength parallel to the grain is a measure of the ability of timber to resist slipping of one part upon another along the grain. Shearing stress is produced in most uses of timber. It is important in beams, where it is known as horizontal shear—the stress tending to cause the upper half of the beam to slide upon the lower—and in the design of various kinds of joints.

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It is difficult to devise a test that involves only shearing stress. A tensile component perpendicular to the grain of the wood influences the results of tests made by the standard method, but in general, the same effect in varying degree obtains in other methods in use or proposed. In obtaining the average shear values presented, a uniform distribution of stress throughout the shearing area is assumed, although it is not certain that uniformity obtains. The maximum shearing strength also varies with the amount of offset between the shearing force and the line of support of the specimen. Comparable values are obtained by standardizing the test procedure as in this series of tests.

LOAD TO CAUSE SPLITTING, CLEAVAGE (COLUMN 29)

Cleavage is the maximum load required to cause splitting of the standard specimen. It is expressed in pounds per inch of width.

It is evident that the maximum load in cleavage depends on the width and length of the specimen. In order to insure comparable results, the standard length of 3 inches is always maintained. The cleavage strength, like some of the other properties cannot be used directly for calculating required sizes of wood members or in similar design problems, but is useful mainly for comparisons. This test differs from the action of nails in splitting wood when driven, and should not be taken as a criterion of the relative resistance of the different species to such splitting.

MAXIMUM TENSILE STRENGTH, TENSION PERPENDICULAR TO GRAIN (COLUMN 30)

The maximum tensile strength perpendicular to the grain is the average maximum stress sustained across the grain by the wood.

The tabulated values are obtained by dividing the maximum load by the tension area. It is recognized that the tensile stress is not uniformly distributed over the area. Consequently, the values probably do not represent a true tensile strength. They are, nevertheless, useful for comparing species and for estimating the resistance of timber to forces acting across the grain.

VARIABILITY

Variability is common to all materials. If one tests pieces of wire from a roll, the loads necessary to pull the wire apart will vary. Likewise, the breaking strengths of different pieces of the same kind of string or rope are not the same. Materials, however, differ considerably in the amount of variation or the spread of values.

The growing tree is subject to numerous constantly changing influences that affect the wood produced, and it is not surprising that even the clear wood is variable in strength and other properties. The factors affecting tree growth include, soil, moisture, temperature, growing space, and heredity.

Everyone who has handled and used lumber has encountered variability and observed that different pieces even of the same species, are not exactly alike. The differences most commonly recognized are in the appearance, but even greater differences in weight and in strength properties occur and may be of greater importance.

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The variability of wood can be illustrated by considering as an example the data on specific gravity of Douglas fir presented in table 2.

These data show that the specific gravity of the heaviest piece included in the series was nearly twice that of the lightest, and that the number of very heavy and very light pieces is small. Most of the values are grouped closely about the average.

TABLE 2.—*Results of specific gravity determinations on 1,240 samples of Douglas fir (coast type)*

Specific gravity [1] group limits	Pieces in group		Specific gravity [1] group limits	Pieces in group	
	Number	*Percent*		*Number*	*Percent*
0.300 to 0.309	2	0.16	0.460 to 0.469	96	7.74
0.310 to 0.319	7	.56	0.470 to 0.479	74	5.97
0.320 to 0.329	6	.48	0.480 to 0.489	70	5.65
0.330 to 0.339	15	1.21	0.490 to 0.499	56	4.52
0.340 to 0.349	13	1.05	0.500 to 0.509	46	3.71
0.350 to 0.359	23	1.85	0.510 to 0.519	41	3.31
0.360 to 0.369	25	2.02	0.520 to 0.529	30	2.42
0.370 to 0.379	38	3.06	0.530 to 0.539	23	1.85
0.380 to 0.389	47	3.79	0.540 to 0.549	12	.97
0.390 to 0.399	64	5.16	0.550 to 0.559	9	.73
0.400 to 0.409	75	6.05	0.560 to 0.569	10	.81
0.410 to 0.419	85	6.86	0.570 to 0.579	4	.32
0.420 to 0.429	76	6.13	0.580 to 0.589	1	.08
0.430 to 0.439	99	7.98	0.590 to 0.599	3	.24
0.440 to 0.449	100	8.06			
0.450 to 0.459	90	7.26	Total	1,240	100.00

[1] Based on weight when oven-dry and volume when green. Average specific gravity equals 0.445; highest observed specific gravity, 0.549; lowest, 0.308.

The manner in which the values are grouped about an average is called a frequency distribution, from which the chances that a random piece will differ from the average by a given amount can be estimated by computation. Such calculations, for example, assuming that the specific-gravity values conform to a so-called normal distribution, leads to the expectation that one-half of the Douglas fir samples would be within 7.9 percent of the average specific gravity, or within the limits 0.41 and 0.48 inclusive, and that one-fourth would be below 0.41 and one-fourth above 0.48. The figure defining such limits, 7.9 percent in this instance, is called the probable variation. By actual count 654 of the pieces or 52.7 percent of the total number (1,240) have a specific gravity between 0.41 and 0.48, whereas 25.4 percent (315) were below 0.38 and 21.9 percent (271) were above 0.48. Thus, as might be expected, the calculated percentages do not agree exactly with the actual count. Nevertheless, the agreement is sufficiently close to show the value of the theory in estimating the variability.

The range in strength properties can be studied and used as a basis for making estimates in a like manner.

After tests have been made it is, of course, easy to determine from the results the proportion of the test pieces within any given range, but one can only estimate the reliability of the averages and the degree to which this test data applies to other pieces. One would like to know the true average for each species, a quantity which cannot actually be determined. The best that can be done is to assume that the laws of chance are operative and thus estimate the probability of variations of given magnitude from the averages found. Such is the basis of the suggestions for estimating variability by means of data presented herein.

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It would be desirable to present a measure of the variability of each property of each species. However, the extensive calculations involving all properties and species have not been made; and if available, their presentation would be involved. Although it is known that all species are not equally variable, existing information indicates that they are enough alike that estimates made on the assumption that the percentage variability in any one property is the same for all species will be sufficiently accurate for approximate calculations.

The questions that most frequently arise in a consideration of the variability of wood, are of two types:

(1) What is the significance of the differences between average values for two species or what is the likelihood that the averages will be changed a specified amount by additional tests?

(2) What is the range that includes a specified proportion of material of a species, or what is the likelihood that a piece selected at random will be within a specified range?

VARIATION OF AVERAGE VALUES

The probable variations of observed averages from the true averages enables one to appraise the significance of differences between observed averages. The estimated probable variation of the observed average from the true average of a species, when based on different numbers of trees, is given in table 3. The percentage probable variations listed in table 3 being average values for a number of species, an occasional species may be considerably more or less variable than indicated.

TABLE 3.—*Percentages probable variation*[1] *of the observed average from the true average of a species, when based on material from different numbers of trees*

Trees—number	1	2	3	4	5	10	15	20	30	40	50
Specific gravity based on volume when green	4.7	3.3	2.7	2.4	2.1	1.5	1.2	1.0	0.9	0.7	0.7
Shrinkage:											
Radial	11.6	8.2	6.7	5.8	5.2	3.7	3.0	2.6	2.1	1.8	1.6
Tangential	9.0	6.4	5.2	4.5	4.0	2.8	2.3	2.0	1.6	1.4	1.3
Volumetric	8.8	6.2	5.1	4.4	3.9	2.8	2.3	2.0	1.6	1.4	1.2
Static bending:											
Fiber stress at proportional limit	11.2	7.9	6.4	5.6	5	3.5	2.9	2.5	2.0	1.8	1.6
Modulus of rupture	8.9	6.3	5.2	4.5	4	2.8	2.3	2.0	1.6	1.4	1.3
Modulus of elasticity	11.2	7.9	6.4	5.6	5	3.5	2.9	2.5	2.0	1.8	1.6
Work to proportional limit	15.6	11.1	9.0	7.8	7	5.0	4.0	3.5	2.9	2.5	2.2
Work to maximum load	13.4	9.5	7.7	6.7	6	4.2	3.5	3.0	2.4	2.1	1.9
Impact bending:											
Fiber stress at proportional limit	8.9	6.3	5.2	4.5	4	2.8	2.3	2.0	1.6	1.4	1.3
Work to proportional limit	11.2	7.9	6.4	5.6	5	3.5	2.9	2.5	2.0	1.8	1.6
Height of drop	15.6	11.1	9.0	7.8	7	5.0	4.0	3.5	2.9	2.5	2.2
Compression parallel to grain:											
Fiber stress at proportional limit	11.2	7.9	6.4	5.6	5	3.5	2.9	2.5	2.0	1.8	1.6
Maximum crushing strength	8.9	6.3	5.2	4.5	4	2.8	2.3	2.0	1.6	1.4	1.3
Compression perpendicular to grain:											
Fiber stress at proportional limit	13.4	9.5	7.7	6.7	6	4.2	3.5	3.0	2.4	2.1	1.9
Hardness, end	8.9	6.3	5.2	4.5	4	2.8	2.3	2.0	1.6	1.4	1.3
Hardness, side	11.2	7.9	6.4	5.6	5	3.5	2.9	2.5	2.0	1.8	1.6
Shearing strength parallel to grain	6.7	4.7	3.9	3.4	3	2.1	1.7	1.5	1.2	1.1	.9
Tension perpendicular to grain	11.2	7.9	6.4	5.6	5	3.5	2.9	2.5	2.0	1.8	1.6

[1] The percentage probable variation of the average of a species is a figure such that there is an even chance that the true average is within this percentage of the observed average in table 1.

The observed average is always the most probable value of the true average. The importance of the differences between species with

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respect to averages depends on the magnitude of this difference in relation to the probable variation of the averages, as well as on how exacting the strength requirements are for the particular use under consideration.

If the averages of any property of two species of table 1 differ by an amount equal to the probable variation of the difference,[8] there is 1 chance in 4 that the true average for the species which is lower in that property on the basis of present data equals or exceeds the true average of the other. There is also 1 chance in 4 that the true average for the higher species exceeds that of the lower one by as much as twice the observed difference. When the averages differ by amounts that are ½, 1, 2, 3, 4, or 5 times the probable variation of their difference the chances of the true average of the lower species equaling or exceeding the true average of the higher, or of the observed difference being at least doubled are given in the following tabulation:

Multiples	*Chance*
½	1 in 2¾.
1	1 in 4.
2	1 in 11.
3	1 in 46.
4	1 in 285.
5	1 in 2,850.

As an example, consider the average values for modulus of rupture of 9,300 and 9,600 pounds per square inch for Biltmore white ash and blue ash, respectively, in the green condition (table 1). These averages being based on five trees of each species the probable variation according to table 3 is 4 percent. Then 4 percent of 9,300 equals 372, and 4 percent of 9,600 equals 384, the probable variations of these averages. The probable variation of the difference between the averages is then $\sqrt{(372)^2+(384)^2}$ or 535; the observed difference in the averages for modulus of rupture (9,600–9,300) is 300. The ratio of the observed difference to the estimated probable variation being less than 1, it may be estimated from the tabulation that the chance that the true average modulus of rupture for Biltmore white ash equals or exceeds that for blue ash is somewhat greater than 1 in 4. There is the same chance that the true average of blue ash exceeds that for Biltmore white ash by as much as 600 or twice the difference in present average figures as shown in table 1. Therefore, the difference in modulus of rupture between blue ash and Biltmore white ash is not to be regarded as significant.

As a second example, consider the figures for modulus of rupture of 9,400 and 8,300 for sweet birch and yellow birch, respectively (table 1). The figures for sweet birch are based on 10 trees, those for yellow birch on 17. From table 3 the probable variation of the species average for modulus of rupture when based on 10 trees is 2.8 percent and when based on 17 trees it is 2.2 percent. (The figure for 17 trees is taken as between that given for 15 trees and 20 trees). Following the method of the preceding example, the probable variation of the difference between the averages is found to be 320. The difference between the observed averages is 1,100, which is about three and one-half times its probable variation of 320. The tabula-

[8] The probable variation of the difference of two average figures is the square root of the sum of the squares of the probable variations of the averages. The probable variation of the average of any property may be estimated from the figures in table 3.

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tion indicates that the chance that the true average for modulus of rupture of yellow birch would equal or excel that for sweet birch is less than 1 in 46. The importance of such differences will depend on the use to be made of the wood.

VARIATION OF AN INDIVIDUAL PIECE FROM THE AVERAGE

The upper and lower limits for any property within which one-half of the material of a species would be expected to fall may be estimated from the following tabulation.

Estimated probable variation of an individual piece from average for species

Property:	*Percent*
Specific gravity based on volume when green	8
Shrinkage:	
Radial	11
Tangential	10
Volumetric	12
Static bending:	
Fiber stress at proportional limit	16
Modulus of rupture	12
Modulus of elasticity	16
Work to maximum load	23
Impact bending:	
Fiber stress at proportional limit	13
Height of drop	18
Compression parallel to grain:	
Fiber stress at proportional limit	18
Maximum crushing strength	13
Compression perpendicular to grain: Fiber stress at proportional limit	21
Hardness, end	13
Hardness, side	15

As an example, consider the modulus of rupture of red alder, when green, which is found from table 1 to be 6,500 pounds per square inch. The tabulation lists the probable variation for modulus of rupture as 12 percent. Twelve percent of 6,500 is 780; which when subtracted from and added to the average gives limits of 5,720 and 7,280 pounds per square inch. The probable variation is a value associated with the range within which one-half of the material of a species will fall. Consequently, it may be estimated that in red alder approximately one-half of the material would be between 5,720 and 7,280 pounds per square inch in modulus of rupture.

Considered in another way, there is 1 chance in 4 that the modulus of rupture of an individual specimen taken at random will be below 5,720 pounds per square inch, 1 chance in 4 that it will be above 7,280 pounds per square inch, and there are 2 chances in 4 that it will be between 5,720 and 7,280 pounds per square inch. The greater the probable variation, the greater the difference that may be expected in values, and the less the certainty with which the average values can be applied to individual pieces.

It is possible by means of mathematical tables, which are available in numerous texts on the theory of probability or statistical methods, to calculate the proportion of material associated with other ranges or that may be expected to be below or above any specified limit.

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SELECTION FOR PROPERTIES

The fact that a piece of wood differs in properties from another of the same species often makes one more suitable than the other for a specific use. This suggests the possibility of selecting material of a quality best suited to meet specific use requirements. Fortunately, strength is frequently correlated with weight and to a lesser degree with other physical characteristics, and these relationships sometimes afford a basis for grading and selecting for strength.

Aside from weight, the other physical characteristics most usable for selecting on the basis of the strength of the clear wood are proportion of summer wood, rate of growth, hardness, and stiffness. Either visual or mechanical methods, or both, may be employed in appraising the properties. For example, selection may be made at the sawmill so that the heavier, and consequently stronger and harder, pieces go into structural timbers, flooring, or other uses for which the higher measure of these properties particularly adapt them, while the lighter pieces may preferably be used for such purposes as trim or heat insulation; or selection may be made at the lumber yard when material of high weight or that of low weight is desired. By means of selective methods the variability of wood, usually regarded as a liability, can within certain limits be made an asset. Selection on the basis of grades that limit defects is a common practice. Selection on the basis of quality of clear wood is less common, but is frequently very desirable, and offers possibility in the improvement of marketing practice. In any instance defects must of course be considered.

OTHER MECHANICAL PROPERTIES NOT INCLUDED IN TABLE 1

In addition to the data from the tests presented in table 1, information on certain other mechanical properties, principally tension parallel to grain and torsional properties is sometimes needed. A brief discussion of these properties, and of a special toughness test that may be used as an acceptance method follows.

TENSION PARALLEL TO GRAIN

In order to get reliable data on tension along the grain, special care must be exercised in preparing test specimens, and for this and other reasons little information on this property is available. Furthermore, the true tensile strength of wood along the grain is less important in design than other properties because it is practically impossible to devise attachments that permit the tensile strength of the full cross section of a wooden member to be developed.

Available results of tension tests show that generally the ultimate tensile strength considerably exceeds the modulus of rupture. Hence the modulus of rupture may be used as an estimate of the ultimate tensile strength parallel to grain for conditions where a uniform distribution of tensile stress obtains over the net cross section of a member. Uniform stress distribution, however, does not occur in the net tension area of a bolted joint, where it has been found that for softwoods the net tension area must be 80 percent, and for hardwoods 100 percent of the total bearing area under all the bolts (*50*) in the joint.

Table 4 presents the average results of tests in tension parallel to the grain on several species.

TABLE 4.—*Results of tests to determine the ultimate tensile strength parallel to the grain*

Species	Green				Air-dry			
	Moisture content	Tests	Specific gravity[1]	Ultimate tensile strength	Moisture content	Tests	Specific gravity[1]	Ultimate tensile strength
	Percent	*Number*		*Lb. per sq. in.*	*Percent*	*Number*		*Lb. per sq. in.*
Ash, white		1	0.535	16,150				
Beech	53	1	.569	12,530				
Cedar:								
Port Orford	34	34	.393	11,380				
Western red	40	10	.300	6,200	8.8	7	0.323	7,130
Cypress, southern	78	15	.424	8,720				
Douglas fir:								
Coast	24	48	.425	12,980	11.1	8	.444	13,830
"Inland Empire"	30	9	.409	9,380	10.2	1	.474	14,880
Fir:								
Noble	29	11	.353	14,750	10.2	9	.370	13,020
California red	168	14	.373	9,040	10.1	10	.385	10,750
White	48	9	.367	8,030	10.7	6	.382	10,450
Hemlock, western	67	20	.380	9,860	10.9	14	.400	9,820
Maple, sugar	48	5	.577	15,660				
Oak, pin	80	3	.578	16,260				
Pine:								
Loblolly	47	2	.446	11,570	11.6	1	.484	15,050
Ponderosa	69	11	.364	8,320				
Poplar, balsam	106	3	.298	7,940	10.4	2	.351	12,160
Redwood	104	29	.377	9,780	10.7	33	.401	10,920
Spruce:								
Eastern[2]	34	14	.366	13,650	11.7	13	.391	13,670
Sitka	40	17	.385	8,110	9.5	10	.406	11,150

[1] Based on weight when oven-dry and volume at test.
[2] Exact species not known.

Figure 1 illustrates the form of specimen on which table 4 is based. Despite the reduced cross section in the central portion of the length the specimens sometimes fail by shear instead of in tension. Specimens that failed other than in tension are not included in the average values of table 4.

TORSIONAL PROPERTIES

The torsional strength of wood is little needed in design and, except for Sitka spruce, has not been studied extensively. Available results, however, indicate that the shearing stress at maximum torsional load, as calculated by the usual formulas, are approximately one-third greater than the values in table 1 for shearing strength parallel to the grain (*51*).

The effect of duration of stress on torsional strength is pronounced, being greater on the proportional limit than on the maximum torsional strength. With slowly applied loads the proportional limit may be less than 50 percent of the maximum, whereas with quickly applied loads the proportional limit may be 75 percent of the maximum load.

The modulus of rigidity or the modulus of elasticity of wood in shear is a combination of the component moduli along radial and tangential surfaces, and is influenced among other things by the position of the growth rings. The combined moduli are known as the mean modulus of rigidity, which for Sitka spruce is about one-fifteenth the modulus of elasticity along the grain. Scattered tests on other species show a range in values of the mean modulus of rigidity be-

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tween one-fourteenth and one-eighteenth the modulus of elasticity along the grain. Until definite values are available for other species, a ratio of one-seventeenth appears conservative.

A third shear modulus that does not come in play in torsion about an axis parallel to the grain is associated with stresses that tend to roll the wood fibers by each other in a direction at right angles to the grain. This shearing modulus is extremely low but is of little importance in most design.

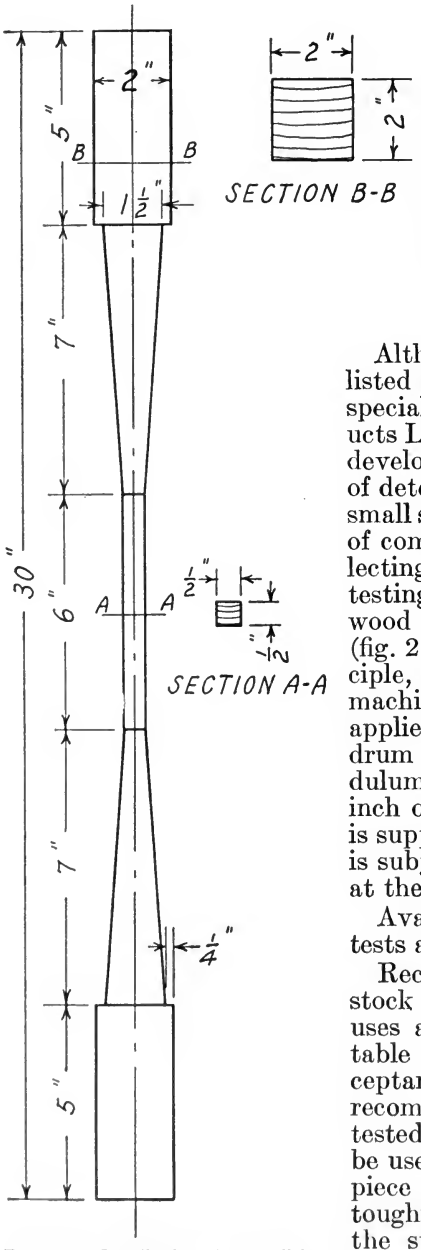

FIGURE 1.—Details of tension-parallel-to-grain test specimen.

TOUGHNESS

Although a number of the properties listed in table 1 measure toughness, a special device known as the Forest Products Laboratory toughness machine was developed to provide a simple method of determining toughness from relatively small samples. The test affords a means of comparing species, and a basis for selecting stock of known properties by testing small specimens from pieces of wood intended for use. The machine (fig. 2) operates on the pendulum principle, but it differs from other pendulum machines in that the striking force is applied through a cable attached to a drum mounted on the axis of the pendulum. The specimen, which is $\frac{5}{8}$ by $\frac{5}{8}$ inch or $\frac{3}{4}$ by $\frac{3}{4}$ inch in cross section and is supported over an 8- or 10-inch span, is subjected to an impact bending force at the middle of its length (*26*).

Available average results of toughness tests are presented in table 5.

Recommended acceptance values for stock for aircraft and other high-class uses are presented for a few woods in table 6. In applying the test as an acceptance requirement for wood, it is recommended that four specimens be tested from the same piece as the part to be used is taken. To be acceptable, the piece (1) must either meet a minimum toughness requirement established for the species under consideration, or if within a certain tolerance below this minimum must pass in addition a minimum specific-gravity requirement; (2) must show a limited range in toughness values for specimens from the same piece, and (3) must pass careful visual inspection.

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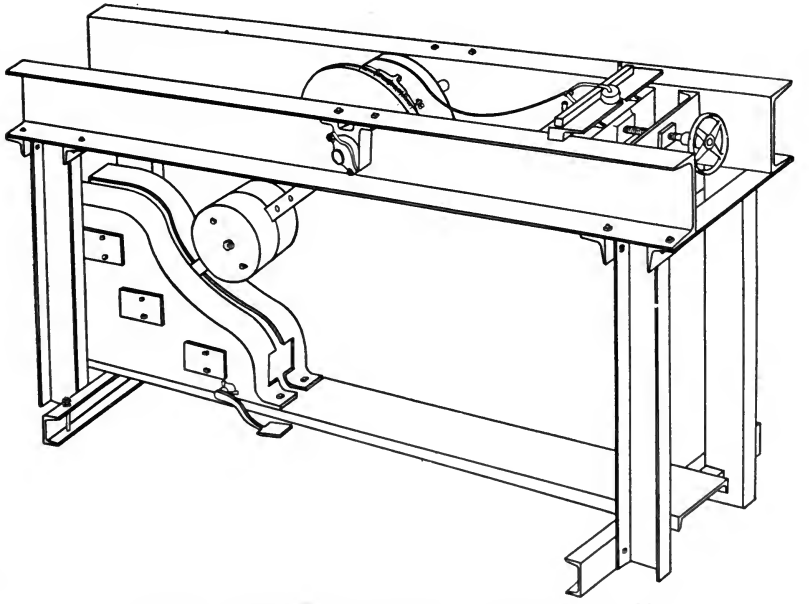

FIGURE 2.—Forest Products Laboratory toughness-testing machine.

TABLE 5.—*Results of toughness tests*

[Specimens 5/8 by 5/8 by 10 inches tested on an 8-inch span]

Species	Moisture content	Specific gravity (oven-dry based on volume at test)	Face to which load is applied			
			Radial		Tangential	
			Tests	Toughness	Tests	Toughness
	Percent		*Number*	*In.-lb. per specimen*	*Number*	*In.-lb. per specimen*
Birch:						
Alaska white	9.8	0.56	14	184	16	180
Yellow	11.9	.65	10	262	11	330
Catalpa, hardy	66	.40	13	180	19	181
	11.8	.41	18	104	17	124
Cedar:						
Alaska	10.4	.48	10	109	10	122
Western red	9.2	.33	21	45	21	70
Douglas fir	36	.43	51	82	59	112
	10	.46	36	86	36	151
Fir, corkbark	55	.31	44	36	44	52
	9.9	.31	28	36	30	51
Hemlock, eastern	12.3	.41	13	56	13	86
Hemlock, western	11.1	.38	31	60	34	86
Maple, sugar	13.8	.64	11	194	11	192
Oak, pin	11.5	.64	15	226	18	225
Pine, loblolly	86	.47	99	139	206	176
	11.9	.51	174	93	168	149
Pine, longleaf	90	.54	39	183	38	232
	13.3	.57	39	94	43	143
Pine, shortleaf	88	.48	106	140	71	191
	12.9	.50	75	77	71	120
Pine, slash	78	.55	72	185	73	238
	11.6	.59	67	109	63	167
Redwood	103	.39	101	58	96	106
	11.4	.39	104	49	99	75
Spruce, Sitka	9.8	.44	33	83	37	121

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TABLE 6.—*Minimum acceptance requirements for aircraft woods based on tests* [1] *in the Forest Products Laboratory toughness machine*

Species of wood	Size of specimen	Span	Minimum average acceptable toughness		
			With specific gravity limitation		Without specific gravity limitation; minimum average toughness [3]
			Minimum specific gravity [2]	Minimum average toughness [3]	
	Inches	*Inches*		*In.-lb. per specimen*	*In.-lb. per specimen*
White ash	5/8 by 5/8 by 10	8	0.56	150	175
Yellow birch	3/4 by 3/4 by 12	10	.58	225	260
Douglas fir	5/8 by 5/8 by 10	8	.45	95	115
White oak	3/4 by 3/4 by 12	10	.62	175	200
Sitka spruce	5/8 by 5/8 by 10	8	.36	75	90
Black walnut	3/4 by 3/4 by 12	10	.52	150	175

[1] Load applied to the tangential face of the specimen.
[2] Based on weight and volume of oven-dry wood.
[3] These values are to be applied to the average of 4 or more test specimens, and the range in individual test values used in arriving at the average should not exceed 1 to 2½ among 4 specimens.

The procedure is simple and tests are made very rapidly. No calculation is necessary as the readings of the machine are readily converted into toughness values by the use of available tables. The procedure is further simplified by the fact that when testing dry wood the moisture condition of the specimen may be ignored, as tests have shown that toughness is affected but little by such moisture differences as may be commonly encountered.

The one essential in the application of the toughness test as an acceptance method, in addition to the necessary machine for making the tests, is a knowledge of the species with respect to minimum toughness requirements. The recommended values presented in table 6 have been established from tests made at the Forest Products Laboratory.

PROPERTIES OTHER THAN STRENGTH

RATING OF SPECIES IN SEVEN PROPERTIES

It has been mentioned that consideration of properties other than strength, weight, and shrinkage may be necessary in appraising the suitability of a wood for various uses (p. 3). Table 7 compares a number of species with respect to ease of kiln drying, ability to stay in place, workability, nail-holding ability, ease of gluing, resistance to decay, and ability to hold paint. The classifications are approximate, and only in some instances are they based on technical research. In others they are based on observation, experience, and general information. The ratings vary from 1 to 4 or 1 to 5, the lowest number indicating the best rating. For some other properties, such as acid resistance, sufficient information is not available to prepare even such a general classification of species. Information on properties other than those presented in this bulletin, insofar as available, may be obtained by writing the Forest Products Laboratory, Madison, Wis.

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TABLE 7.—*Approximate comparison of 7 properties of commercial species of wood*

Key to classification of woods: Columns 2 and 4 represent a gradation of properties in the various woods from those which can be dried and worked with comparative ease (class 1) to those which present some difficulty in those respects (class 4). Column 3 represents a gradation from those woods which possess the greatest ability to stay in place under conditions of actual use (class 1) to those species which do not possess that ability to the same extent (classes 2, 3, 4, in the order named). Column 5 represents a gradation from those which possess the greatest nail-holding power but have the greatest tendency to split (which necessitates the use of smaller nails) to those having the least nail-holding ability but which are less likely to split. In column 6 the woods in class 1 are known to be used commercially in glued construction. Class 2 includes species about which little is known but which are not believed to be difficult to glue. Class 3 includes species which are known to require a little more attention in gluing than class 1 woods in order to get best results. Class 4 includes woods which are known to present real difficulties in gluing, and class 5 those species about which little is known but which it is believed would present some difficulties in view of their similarity to species of known properties. Column 7 presents comparative values for resistance to decay of heartwood when used under conditions that favor decay, class 1 being most decay-resistant. Column 8 represents a classification of softwood species with respect to ability to hold paint when used outside, class 1 species holding paint the most satisfactorily. Ability to hold paint is more important for outside than for inside use. The hardwood species are not commonly used for exterior work requiring painting and have not yet been classified]

Species	Ease of kiln drying [1]	Ability to stay in place	Work-ability	Nail-holding ability	Ease of gluing	Resist-ance to decay (heart-wood)	Ability to hold paint
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
HARDWOODS							
Alder, red	2	3	2		1		
Ash:							
Black	3	4	3				
White	2	3	4	2	3	4	
Aspen	2	3	2	5	2	5	
Basswood	2	3	2	5	1	5	
Beech	4	4	4	1	5	4	
Birch:							
Paper	2	4	3		5		
Sweet and yellow	2	4	4	1	3	4	
Buckeye, yellow			2		2		
Butternut	2	2	2		2		
Cascara			4				
Cherry:							
Black	4	3	3				
Pin	3	3	2		2		
Chestnut	2	2	2	4	1	1	
Chinquapin, golden			3				
Cottonwood:							
Black	3	4	2	5	1	5	
Eastern	2	4	2	5	1	5	
Dogwood	2	5	5	1	5		
Elm:							
American	3	5	4	3	1		
Rock	3	5	4				
Gum:							
Black	3	5	4		2	5	
Red	[2] 2, 4	4	4	3	1	3	
Hackberry	2	4	3		2		
Hickory, shagbark	4	5	5	1	4		
Honey locust	4	2	4	1	5	2	
Hophornbeam	3	5	5	1	5		
Laurel, California	5	3	4		5		
Madrone, Pacific	4	5	4		5		
Magnolia, cucumber	3	4	3	3	1		
Maple:							
Bigleaf	3	3	3		5		
Red	3	3	4		5		
Sugar	3	4	4	1	3	4	
Oak:							
California black	4	3	4		5		
Red	[3] 4, 5	4	4	1	3	4	
White	[3] 4, 5	4	4	1	1	2	
Persimmon	4	4	5	1	4		
Poplar, yellow	2	2	2	4	1		
Sycamore	4	4	4	2	2		
Walnut, black	4	2	3		1	1	
Willow, black	2	3	2		2	5	

[1] Softwoods are in general easier to dry than hardwoods. A softwood given the same numerical rating a a hardwood is, therefore, regarded as slightly easier to dry. These ratings are based on ease of removal of moisture without visible degrade but do not take into account susceptibility to reduction in strength in drying under high temperatures (*57*).

[2] 2 refers to sapwood and 4 to heartwood, known commercially as sap gum and red gum, respectively.

[3] 4 refers to the upland type of oak and 5 to the lowland type of oak.

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TABLE 7.—*Approximate comparison of 7 properties of commerical species of wood*—Continued

Species	Ease of kiln drying	Ability to stay in place	Work-ability	Nail-holding ability	Ease of gluing	Resist-ance to decay (heart-wood)	Ability to hold paint
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
SOFTWOODS							
Cedar:							
Alaska	1	1	3	----------	2	1	1
Incense	1	1	2	----------	2	1	1
Northern white	2	1	2	5	2	1	1
Port Orford	2	2	3	----------	2	1	1
Western red	[4] 2, 3	1	2	5	2	1	1
Cypress, southern	3	2	3	3	2	1	1
Douglas fir	1	3	4	3	1	[5] 2, 3	4
Fir:							
Alpine and balsam	1	----------	2	5	2	5	3
Grand, noble and white	1	3	2	5	2	5	3
Hemlock:							
Eastern	2	3	3	4	2	4	3
Western	2	3	3	3	1	4	3
Larch, western	3	3	4	3	2	3	4
Pine:							
Jack	1	3	3	4	2	----------	3
Lodgepole	1	2	2	5	2	----------	3
Northern white	2	1	1	4	1	----------	2
Norway	1	3	2	3	2	----------	3
Pitch	1	3	4	3	2	3	4
Ponderosa	1	2	2	4	1	----------	3
Southern yellow	1	3	4	2	1	[5] 2, 3	4
Sugar	2	1	1	----------	1	----------	2
Western white	3	2	2	4	1	----------	2
Redwood	[6] 3, 4	2	3	4	1	1	1
Spruce:							
Engelmann	2	2	2	5	2	4	3
Red and white	1	2	2	4	1	4	3
Sitka	1	2	2	4	1	4	3
Tamarack	2	3	4	----------	2	3	3

[4] 2 refers to material from upper logs and 3 to material from butt logs which are generally susceptible to collapse.
[5] 2 refers to dense Douglas fir and dense southern yellow pine.
[6] 3 refers to material from upper logs and 4 to sinker stock from butt logs.

REQUIREMENTS FOR MOISTURE CONTENT OF WOOD IN BUILDINGS

The satisfactory use of lumber frequently depends upon the characteristics of the stock in its entirety, such as the size, kind, and number of defects as well as upon the properties of the clear wood, and may be further influenced by sizes available, degree of seasoning, and marketing practices. For most purposes seasoned is to be preferred to unseasoned stock, and for some uses, such as flooring, a definite degree of seasoning is essential for satisfactory results.

As an example of seasoning requirements, table 8 gives recommendations for desirable initial moisture content of lumber for various parts of dwellings (*40*).

While it is desirable that the average moisture content be near the value given in table 8, it is far more important that the moisture content of individual pieces of a lot be within the specified range.

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TABLE 8.—*Recommended moisture-content values for various wood items at time of installation*

Use of lumber	Moisture content (percentage of weight of oven-dry wood) for—					
	Dry southwestern States		Damp southern coastal States		Remainder of the United States	
	Average	Range for individual pieces	Average	Range for individual pieces	Average	Range for individual pieces
Interior finishing woodwork and softwood flooring	6	4–9	11	8–13	8	5–10
Hardwood flooring	6	5–8	10	9–12	7	6–9
Sheathing, framing, siding, and exterior trim	9	7–12	12	9–14	12	9–14

MOISTURE CONTENT OF HEARTWOOD AND SAPWOOD

Average moisture-content values from green specimens consisting entirely of sapwood, or entirely of heartwood, are listed in table 9, for a number of species. These values show the variation in moisture content among species, the relative equality in moisture content of heartwood and sapwood in several hardwoods, and the large differences commonly existing in softwoods.

TABLE 9—*Average moisture content for green heartwood and sapwood of 19 species*

Species	Trees	Average moisture content		Species	Trees	Average moisture content	
		Heartwood	Sapwood			Heartwood	Sapwood
HARDWOODS	*Number*	*Percent*	*Percent*	SOFTWOODS—contd.	*Number*	*Percent*	*Percent*
Ash, white	12	38	40	Hemlock:			
Beech	6	53	78	Eastern	5	58	119
Birch, yellow	9	68	71	Western	13	42	170
Elm, American	3	95	92	Pine:			
Gum, black	4	50	61	Loblolly	8	34	94
Maple:				Lodgepole	5	36	113
Silver	4	60	88	Longleaf	18	34	99
Sugar	6	58	67	Norway	4	31	135
	5	36	117	Ponderosa	4	40	148
SOFTWOODS	3	91	136	Shortleaf	8	34	108
				Spruce:			
Douglas fir	5	36	117	Engelmann	2	54	167
Fir, lowland white	3	91	136	Sitka	2	33	146

The moisture content of green heartwood and sapwood varies greatly among trees, and varies within the tree at different heights. The sapwood of the softwood species was consistently higher in moisture content than the heartwood, but some hardwood trees were found in which the heartwood was slightly higher than the sapwood. Because of the variation in moisture content of green wood, the values presented should not be taken as rigid averages for the species, but rather as indications of what may be expected.

The values in table 9 may be used in specific instances to estimate the average moisture content of logs. For example, if ponderosa pine logs in a shipment are observed to have 75 percent of sapwood

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by volume, the average moisture content would be estimated as $(0.75\times148)+(0.25\times40)=121$ percent. Average moisture-content values computed in this way are likely to be more accurate in such instances and a better basis for computing weights than the average values listed for green material in column 7 of table 1 as these latter values may represent a quite different proportion of sapwood. The proportion of sapwood and heartwood in trees varies with the age of the stand and with growth conditions.

OTHER DATA ON SPECIFIC GRAVITY

In addition to the data on the specific gravity of the wood subjected to strength tests as presented in table 1, the Forest Products Laboratory has obtained for 14 common softwood species information based on sections of boards collected at sawmills in various parts of the United States (*41*). For a number of species the sampling from sawmills was more extensive than that used in obtaining specimens for strength tests, and the data are of interest on that account. In addition, data on heartwood and sapwood were segregated, whereas this has not been done with the data from the standard series of strength tests.

The principal data from the study of samples collected at sawmills are shown in table 10.

TABLE 10.—*Comparison of specific gravity (oven-dry, based on volume when green) of mill-run samples with that of specimens used for mechanical tests*

Species	Mill-run samples [1]					Specimens for mechanical tests		
	Specimens	Specific gravity heartwood and sapwood combined	Probable variation	Specific gravity heartwood	Specific gravity sapwood	Trees	Specimens	Specific gravity
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Number		*Percent*			*Number*	*Number*	
Cypress, southern	377	0.38	10.0	0.39	0.36	26	479	0.42
Douglas fir:								
Washington and Oregon	2,764	.44	8.1	.44	.43	34	1,029	.45
"Inland Empire"	176	.44	6.6			10	113	.41
Fir: White	[1] 1,187	[1] .33	[1] 7.1	[1] .33	[1] .33	45	278	.35
Hemlock, western	1,359	.39	6.8	.39	.39	18	689	.38
Larch, western	820	.45	7.5	.45	.43	13	214	.48
Pine:								
Longleaf	[1] 5,396	[1] .52	[1] 10.3	[1] .57	[1] .48	34	806	.55
Northern white	386	.34	5.7	.35	.34	18	299	.34
Norway	121	.39	6.6	.39	.38	5	126	.44
Ponderosa	1,876	.37	8.7	.38	.36	31	579	.38
Shortleaf	[1] 4,357	[1] .47	[1] 8.5	[1] .51	[1] .46	[2] 22	[2] 1,190	[2] .49
Sugar	965	.33	6.7	.33	.32	9	191	.35
Western white	1,178	.36	5.9	.36	.36	14	211	.36
Redwood	585	.36	9.7	.36		16	564	.39
Spruce, Sitka	658	.36	6.9	.36	.33	25	1,392	.37

[1] The mill-run specimens were classified according to commercial species designations of the lumber and not according to botanical classification, although in most instances the two are approximately the same. The southern pines are the principal exception as there is no known method of distinguishing the several species botanically from the wood alone, and hence species are mixed in the commercial designations. The samples used for mechanical tests were taken from trees identified botanically in the woods.

[2] Values for shortleaf and loblolly pine combined.

It was not possible in all cases to identify these samples as to species. Consequently, the data are classified according to commercial designation of the lumber and not according to exact species. However, except for those names to which footnote 1 is appended, the designations are probably the correct species names.

Table 10 shows for comparison values of specific gravity taken from column 8 of table 1. In general, the values in columns 3 and 9 of table 10 are in reasonable agreement although with but two exceptions (western hemlock and Douglas fir from the "Inland Empire" region) those of column 9 are the same or higher. Other studies have disclosed considerable variation in Douglas fir in the "Inland Empire" region and in this instance the operation of chance in sampling might readily lead to the difference between the values in columns 3 and 9. Further reasons for differences include the effect of position of material in the tree, and the fact that the methods of determining specific gravity were not quite identical.

The specimens used for standard strength tests (column 9) were taken mainly from the top 4 feet of 16-foot butt logs, whereas the samples collected at the mill (column 3) represent mixed material in which wood from all parts of the tree may be included. Because in many species the wood near the butt of the tree is heavier than that from the upper portions of the trunk, the specific-gravity values in column 9 would in general be expected to be slightly higher than those representing mixed material. An example of this kind is afforded by western larch. The butt portions of western larch trees contain large quantities of extractives which increase the weight considerably and as much as 12 feet of the portion immediately above the stump is often discarded because the extra weight makes handling of the logs difficult. On the other hand, Sitka spruce is an example of a species whose specific gravity varied but little with height in tree.

In general, the differences between the values listed in columns 3 and 9 are not greater than are to be expected from the causes just discussed combined with the effects of chance in sampling.

Table 10 also lists some data on the specific gravity of heartwood and sapwood, and the probable variation in specific gravity of the mill samples. It may be noted that the specific gravity of heartwood is in general slightly higher than that of sapwood. One reason for this higher value is the greater quantity of extractives (p. 47) in the heartwood.

FACTORS AFFECTING THE STRENGTH OF WOOD

The numerical data presented in table 1 were, as has been shown, derived from tests of small clear specimens taken from a specific part of the tree and tested under a standardized procedure.

Most uses of wood involve pieces differing in size and shape from those tested; clear material may not be available or may be more expensive than a contemplated use justifies; conditions of use may differ radically from standard test conditions; time limitations may require kiln drying; need for permanence may point to preservative treatment; the user may have erroneous concepts of the rate of growth as a criterion of suitability or of the comparative strength of heartwood or sapwood; he may hesitate to accept material from dead trees, or from turpentined trees. These and many other questions

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that may arise require consideration in order to properly interpret the numerical data and adapt it to specific uses of wood. A knowledge of factors affecting strength is thus essential to the interpretation of test data and is of value in the purchase of lumber, in the preparation of specifications covering the use of timber in engineering structures, and in the selection, classification, and use of wood for manufactured products. A brief discussion of various factors affecting the strength of wood is accordingly presented.

RELATION OF PROPERTIES TO STRUCTURE

Wood is a heterogeneous material consisting essentially of fibers of cellulose cemented together by lignin. The fibers, which taper toward the ends, are about one-eighth of an inch long in softwoods, one twenty-fourth of an inch in hardwoods, with a central diameter about one hundredth of the length. They are hollow, their longer dimension running lengthwise of the tree. In the softwoods the fibers act as water conductors. In the hardwoods a limited number of fibers act similarly and there are also relatively large pores or vessels which serve the same function. Besides these vertical fibers which comprise the principal part of the wood, all woods except palms and yuccas contain horizontal strips of cells known as rays or wood rays which are oriented radially and are an important part of the tree's food transfer and storage system. Among different species the rays differ widely in their size and prevalence.

The shape, size, and arrangement of the fibers, the presence of the wood rays, and the layer effect of spring and summer wood make wood a nonisotropic material with large differences in the properties along and across the grain (*19*, *43*). Certain of the properties across the grain may be but a small fraction of the like properties along the grain. In air-dry Sitka spruce, for instance, the modulus of elasticity across the grain, may be only one one-hundred-and-fiftieth as great as when the load is parallel to the grain (10,200 pounds per square inch for 45° angle (p. 35) as compared to 1,570,000 pounds per square inch in column 16, table 1). There is an increasing need for information which will permit a closer correlation of structure and properties. Such information is of value in accounting for and remedying and preventing certain difficulties in the use of wood, and for giving a more precise basis for timber design through a better knowledge of properties and stress distribution.

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TABLE 11.—*Average results of tests showing influence of position of growth rings on the mechanical properties of Sitka spruce, Douglas fir, and loblolly pine*

Properties	Sitka spruce				Douglas fir				Loblolly pine, green	
	Green		Air-dried		Green		Kiln-dried			
	Position A [1]	Position B [1]	Position A [1]	Position B [1]	Position A [1]	Position B [1]	Position A [1]	Position B [1]	Position A [1]	Position B [1]
Static bending:										
Moisture—percent [2]	45.2	45.3	12.2	12.2	30.6	29.4	11.9	11.9	26.0	25.8
Specific gravity [3]	.341	.343	.370	.372	.427	.431	.455	.459	.599	.599
Fiber stress at proportional limit—pounds per square inch	3,160	3,150	5,800	5,900	4,510	4,700	7,800	8,120	4,820	4,540
Fiber stress at maximum load—pounds per square inch	4,890	4,960	8,470	8,450	7,280	7,470	10,630	10,860	9,750	9,740
Modulus of elasticity—1,000 pounds per square inch	1,104	1,124	1,370	1,374	1,475	1,480	1,723	1,713	1,398	1,398
Work to proportional limit—inch-pounds per cubic inch	.52	.52	1.46	1.49	.81	.86	2.03	2.22	1.00	.90
Work to maximum load—inch-pounds per cubic inch	5.2	5.6	7.5	7.5	6.3	7.6	7.4	7.5		
Work, total—inch-pounds per cubic inch	15.8	14.4			15.0	11.9				
Impact bending, 50-pound hammer:										
Moisture—percent [2]	45.8	44.4	12.7	12.5	30.4	30.3	10.7	11.0		
Specific gravity [3]	.343	.350	.372	.378	.422	.431	.457	.460		
Fiber stress at proportional limit—pounds per square inch	7,870	7,860	10,150	9,900	8,870	9,450	12,550	12,370		
Modulus of elasticity—1,000 pounds per square inch	1,277	1,274	1,618	1,662	1,480	1,729	2,140	2,110		
Work to proportional limit—inch-pounds per cubic inch	2.7	2.7	3.7	3.4	3.0	2.9	4.2	4.1		
Height of drop causing complete failure—inches	20	20	21.0	20.9	20.4	18.8	[4] 23.4	[4] 23.1		
Compression parallel to grain:										
Moisture—percent [2]	45.2	46.4	12.7	12.7	29.6	29.2	10.2	10.4		
Specific gravity [3]	.339	.341	.363	.370	.428	.419	.451	.459		
Rings per inch	14.5	15.7	6.5	7.6	16.3	15.9	20.4	23.0	7.0	7.5
Fiber stress at maximum load—pounds per square inch	2,220	2,210	4,490	4,670	3,810	3,730	7,230	7,250	4,680	4,650
Hardness [5]:										
End—pounds	357	357	682	701	440	440	713	713		
Side—pounds	289	283	436	462	452	446	700	657		
Compression perpendicular to grain: Fiber stress at proportional limit—pounds per square inch	227	227	548	582	455	496	609	667		
Shear parallel to grain: Shearing strength—pounds per square inch	713	668	184	1,202	883	833	1,209	1,266		
Cleavage: Cleavage strength—pounds per square inch	122	94	242	189	133	136	163	163		
Tension at right angles to grain: Tensile strength—pounds per square inch	208	130	466	357	179	165	255	307		

[1] Position A and B refer to placement of growth rings with respect to directions of application of load, as illustrated in fig. 3.
[2] Percent moisture based on weight of oven-dry wood.
[3] Specific gravity based on weight when oven-dry and volume at test.
[4] Adjusted to drop for 2- by 2-inch cross section.
[5] Load required to imbed a 0.444-inch ball to ½ its diameter.

POSITION OF GROWTH RINGS

In the sawing of lumber and timber the position of the growth rings may be made to assume different directions with respect to the surfaces of the piece. Any effect of position of growth rings on the properties thus assumes practical significance.

Table 11 presents, for three species, data on clear specimens 2 by 2 inches in cross-section tested to determine the effect of two positions of growth rings on the strength properties (fig. 3). It may be noted

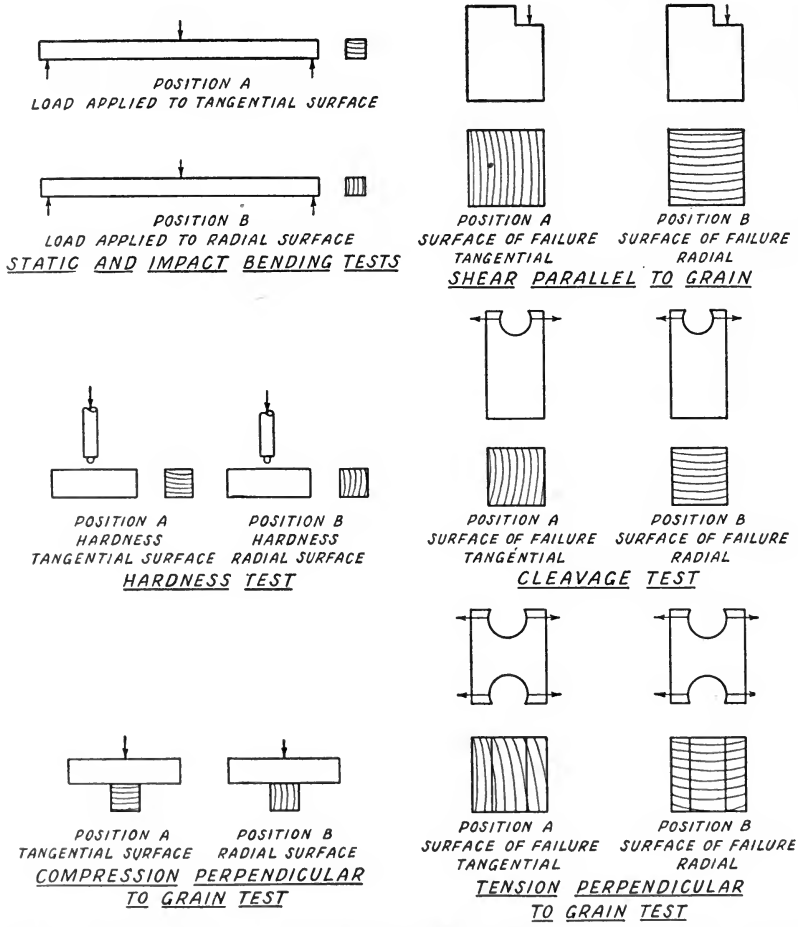

FIGURE 3.—Sketch of standard mechanical tests which afford choice in placement of growth rings with respect to direction of application of load.

that the bending tests, which were on specimens 30 inches long, show little difference in the properties listed, whether the rings as viewed on the end of a piece are vertical or horizontal. Some of the other properties listed, however, show significant differences between the two placements of rings resulting not only from the difference in structure due to the rings themselves, but also the difference orientation of the other minute structural elements of the wood with respect to the direction of stress.

The values from the tests in compression parallel to grain, which were unaffected by the placement of growth rings because the specimens were square, together with the data on specific gravity and rings per inch, show that the wood representing position A was practically identical in quality with that representing position B.

There are many further effects of stratified structure on properties, as evidenced by the growth-ring position, not brought out by results of standard tests. An outstanding example is in compression perpendicular to grain. The results of some preliminary determinations of modulus of elasticity in compression perpendicular to grain are presented in table 12.

TABLE 12.—*Modulus of elasticity in compression perpendicular to grain as influenced by direction of growth rings*

[Specimens 1½ by 1½ by 6 inches loaded on the 1½ by 1½-inch face]

Species	Specific gravity	Moisture content	Modulus of elasticity when the growth rings with respect to the applied load are at an angle of—				
			0°	22½°	45°	67½°	90°
		Percent	*Lb. per sq. in.*	*Lb. per sq. in,*	*Lb. per sq. in.*	*Lb. per sq. in.*	*Lb. per sq. in.*
Redwood	0.34	11	78,400	28,600	17,100	27,900	106,600
Douglas fir	.45	37	58,200	21,400	12,200	26,800	85,400
Spruce, Sitka	.42	13	62,400	18,100	10,200	22,400	110,300
Hemlock, western	.44	88	45,400	11,600	8,300	14,100	71,500
Birch, yellow	.68	63	48,000	39,900	34,000	55,900	81,200
Do	.67	13	106,400	82,300	80,800	113,200	158,000
Oak, red	.56	119	66,200	57,800	59,700	77,400	110,300

It may be noted that there is a large difference in the modulus of elasticity in compression perpendicular to grain with position of rings, amounting to as much as 11 to 1 in Sitka spruce between material with the rings at 90° to the direction of the load and that with rings at 45°. Proportional limit and maximum crushing strength perpendicular to grain are also affected by ring position, although the indications are that the differences are considerably less than for modulus of elasticity.

In the Forest Products Laboratory toughness test, in which specimens one-half to three-fourths inch square and 10 to 12 inches long are used, some marked differences have been found, depending on whether the load is applied to the radial or tangential face. In some species avarage differences of as much as 50 percent of the lesser values were noted (table 5), the higher values resulting when the load was applied to the tangential face. These results as compared with those of table 11, indicate that size of specimen may be an important factor in the influence of position of rings.

SPRING WOOD AND SUMMER WOOD PLACEMENT EFFECT

Significant differences with ring placement may become evident in properties not appreciably affected in 2- by 2-inch pieces when specimens of smaller size are tested. This was demonstrated by static-bending tests on 1- by 1- by 16-inch specimens of southern yellow pine and Douglas fir containing large amounts of summer wood, modulus of elasticity being determined (without stressing the specimen beyond the proportional limit) by placing the specimen with the

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rings horizontal and then vertical. The modulus of elasticity of specimens with summer wood layers on the two faces averaged 12 percent higher for southern yellow pine, and 16 percent higher for Douglas fir with the rings horizontal (load applied to tangential face) than with the rings vertical (load applied to radial face). On the other hand, with specimens having spring wood layers on two faces, the modulus of elasticity when the rings were horizontal (load applied to the tangential face) averaged 9 percent lower than when the rings were vertical (load applied to radial face) for southern yellow pine and 13 percent lower for Douglas fir. These differences, it should be observed, represent a spring wood and summer wood placement effect rather than a pure growth-ring placement effect. Theoretical calculations based on the assumption of widely different properties in spring wood and summer wood check these observed values closely.

SPECIES OF WOOD

Some species of wood differ greatly from others in their average specific gravity, strength, and other properties. Certain species, such as hickory and ash, excel in toughness and shock-resisting ability. Others, such as southern yellow pine and Douglas fir, are high in bending strength and stiffness for their weight. Still other species are soft, uniform in texture, and easy to work. Such differences permit a choice of species to meet the requirements of diverse and exacting uses. Comparative data on important properties are presented for 164 species of wood in table 1.

The average differences in strength properties between species ordinarily competing for the same use are often quite small. Nevertheless, there may be decided differences in structure and in behavior with respect to moisture relations, drying, and manufacturing characteristics which make it necessary to vary the handling procedure or manufacturing practice to best suit the wood under consideration. In this way as satisfactory service may be obtained from species not generally regarded so suitable for a use as from species that give a good account of themselves regardless of care or of lack of care in their handling.

SPECIFIC GRAVITY (OR DENSITY) AS RELATED TO STRENGTH

The substance of which wood is composed is actually heavier than water, its specific gravity being about 1.5 regardless of the species of wood. In spite of the fact that the actual wood substance is heavier than water, the dry wood of most species floats in water, and it is thus evident that a considerable portion of the volume of a piece of wood is occupied by cell cavities and pores. The specific gravity of a piece of dry wood is thus an excellent index of the amount of wood substance it contains and hence is an index of the strength properties.

The relations between specific gravity and other properties of wood may be considered on the basis of (1) different species and (2) different pieces of the same species.

SPECIFIC GRAVITY-STRENGTH RELATIONSHIP AMONG SPECIES

The general relation of specific gravity to strength is illustrated by two widely different woods, mastic, a very heavy species growing in Florida, and balsa, a very light species from Central America. Compression-parallel-to-grain tests on green material gave the results in

table 13, and show that mastic with average specific gravity 9 times as great as that of balsa was 9 times as high in crushing strength along the grain. Weight for weight, the crushing strength parallel to grain of these diverse species are substantially equal.

TABLE 13.—*Comparison of the specific gravity and the maximum crushing strength of mastic and balsa*

Species	Specific gravity, based on weight and volume of wood when oven dry	Maximum crushing strength parallel to grain	Specific strength (column 3÷column 2)
(1)	(2)	(3)	(4)
		Lb. per sq. in.	
Mastic	1.03	5,880	5,710
Balsa	.11	644	5,850

The average specific gravity-strength relations based on 163 species of hardwoods and softwoods show that some properties, such as maximum crushing strength parallel to grain, increase approximately in proportion to the increase in specific gravity, whereas others increase more rapidly. Modulus of rupture, for instance, varies from one species to another as the 1¼ power of specific gravity. Other properties are related to specific gravity by equations of still higher powers; for example, the exponent of specific gravity for relation to hardness is 2¼. It is evident, therefore, that small differences in specific gravity may result in large differences in certain strength properties. For example, one species twice as high in specific gravity as another has 4¾ times the hardness.

Approximate average relations of specific gravity to strength properties among different species are given in table 14 (*38*).

TABLE 14.—*Specific gravity-strength relations among different species* [1]

Property	Unit	Moisture condition	
		Green	Air-dry (12-percent moisture content)
Static bending:			
Fiber stress at proportional limit	Pounds per square inch	$10200G^{1.25}$	$16700G^{1.25}$
Modulus of rupture	do	$17600G^{1.25}$	$25700G^{1.25}$
Work to maximum load	Inch-pounds per cubic inch	$35.6G^{1.75}$	$32.4G^{1.75}$
Total work	do	$103G^{2}$	$72.7G^{2}$
Modulus of elasticity	1,000 pounds per square inch	$2360G$	$2800G$
Impact bending:			
Fiber stress at proportional limit	Pounds per square inch	$23700G^{1.25}$	$31200G^{1.25}$
Modulus of elasticity	1,000 pounds per square inch	$2940G$	$3380G$
Height of drop	Inches	$114G^{1.75}$	$94.6G^{1.75}$
Compression parallel to grain:			
Fiber stress at proportional limit	Pounds per square inch	$5250G$	$8750G$
Maximum crushing strength	do	$6730G$	$12200G$
Modulus of elasticity	1,000 pounds per square inch	$2910G$	$3380G$
Compression perpendicular to grain: Fiber stress at proportional limit.	Pounds per square inch	$3000G^{2.25}$	$4630G^{2.25}$
Hardness:			
End	Pounds	$3740G^{2.25}$	$4800G^{2.25}$
Radial	do	$3380G^{2.25}$	$3720G^{2.25}$
Tangential	do	$3460G^{2.25}$	$3820G^{2.25}$

[1] The values listed in this table are to be read as equations, for example: Modulus of rupture for green material $=17600G^{1.25}$, where G represents the specific gravity, oven-dry, based on volume at moisture condition indicated.

Some species of wood contain relatively large amounts of resins, gums, and other extractives, which add to the weight but do not contribute so much to the strength as would a like amount of wood substance (*23*). In addition, species vary in the structural arrangement of their fibers. For these reasons, two species which average the same in specific gravity may exhibit different strength character-

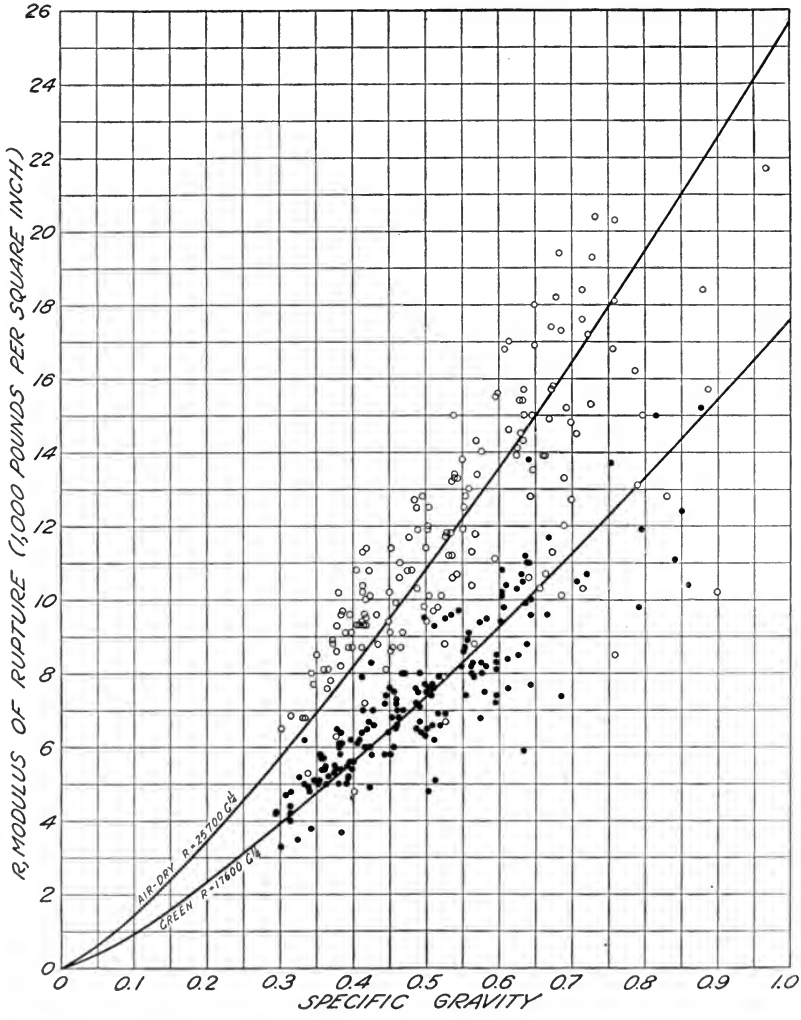

FIGURE 4.—Relation of modulus of rupture to specific gravity for green and air-dry material of various species.

istics. This fact is illustrated by the scattering of the points in figure 4. The values for Douglas fir (coast type) and red gum in table 1 illustrate an extreme example of variations from the average density-strength relations among species. Although these woods are about equal in weight per unit volume when dry, Douglas fir averages 39 percent higher in compressive strength but considerably lower than red gum in shock resistance.

It is true, likewise, that some species of wood are equal in some respects to others of higher density. Douglas fir (coast type), although its density is but three-fourths that of commercial white oak, is about equal to the oak in bending and compressive strengths, and excels it in stiffness. However, the oak averages much higher than Douglas fir in hardness and shock resistance. Hence the specific gravity relationships among species represent general trends and not uniform laws. Departure of a species from the general relationship often indicates some exceptional characteristic which makes this species particularly desirable for certain use requirements.

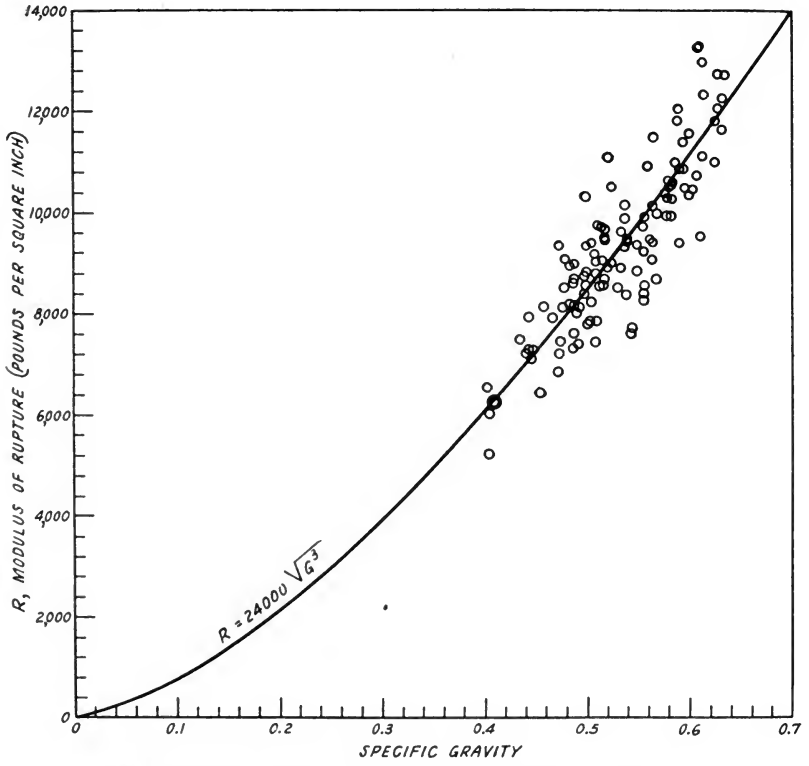

FIGURE 5.—Relation of modulus of rupture of white ash (green) to specific gravity.

SPECIFIC GRAVITY-STRENGTH RELATIONSHIP AMONG INDIVIDUAL PIECES OF A SPECIES

While a general relationship thus exists between the specific gravities and strength properties among different species, specific gravity affords a still better index of strength within a species. The heaviest pieces of any species of wood are generally 2 to 3 times as high in specific gravity as the lighter ones of the species, and are correspondingly stronger. The relationship of pieces within a species is usually represented by a power of specific gravity slightly higher than that representing average values for different species. Furthermore, departures from the average relationship are less marked. Figure 5 illustrates the relation between the specific gravity and the modulus of rupture for individual pieces of white ash.

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THE TREE IN RELATION TO STRENGTH

HEIGHT IN TREE

The wood from the butt of the trees of many species is higher in specific gravity than that from higher positions. Since wood of higher specific gravity usually has the better mechanical properties regardless of position in tree, the height in tree ordinarily needs to be taken into account only in connection with other factors (fig. 6). Sometimes, however, notably in hickory and ash, material from the

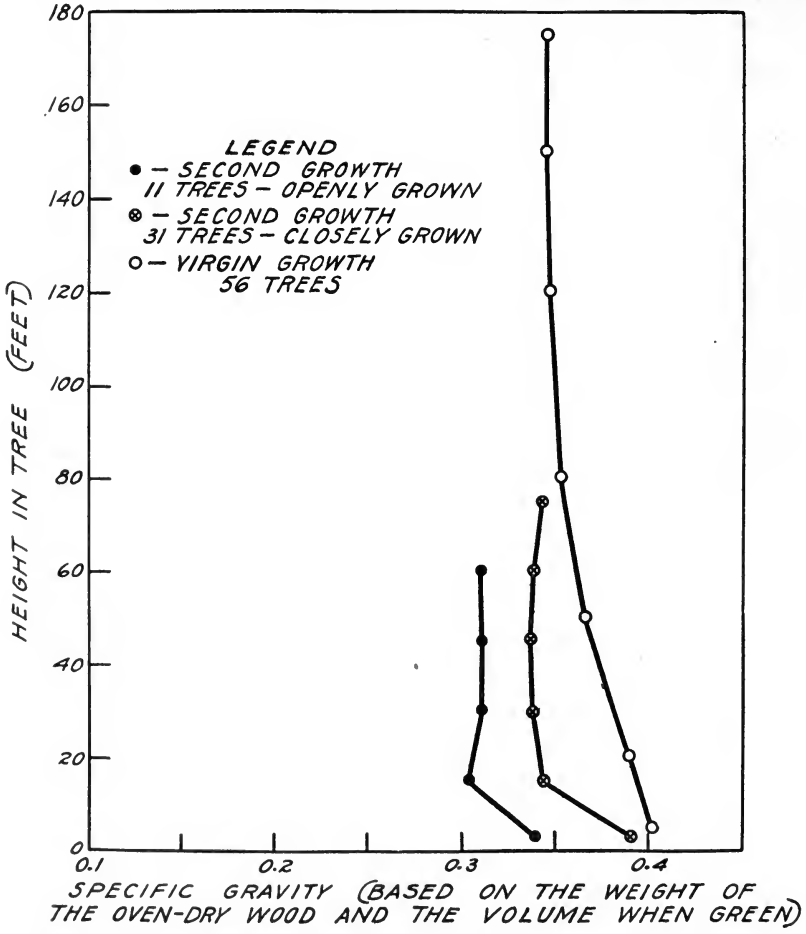

FIGURE 6.—Variation in specific gravity with height for virgin-growth and second-growth redwood.

butt shows superior toughness or shock resistance for its weight. On the other hand, wood from the swelled butts of certain swamp-grown hardwoods is usually low in specific gravity and of inferior strength properties, whereas that above the swelled butt is more nearly normal.

POSITION IN CROSS SECTION OF TREE

Position in cross section is not in itself a reliable guide to the strength of the wood. As in other instances, the wood of highest specific gravity has the best strength properties.

In coniferous species wood near the pith of the tree is often of very rapid growth and low specific gravity, whereas that in the outer part of overmature trees is of slow growth and likewise of medium to low specific gravity, the wood of highest strength most frequently being that in the intermediate zone. The many factors influencing growth, however, result in wide diversity of wood formation and preclude the drawing of rigid general rules (fig. 7).

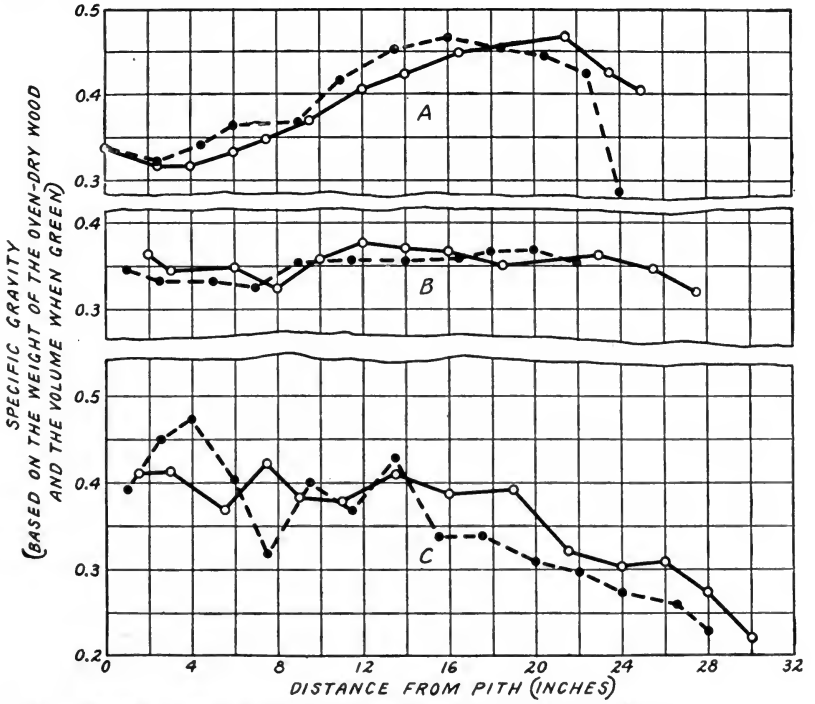

FIGURE 7.—Variation of specific gravity with distance from the pith for three different virgin-growth redwood trees at a height of 20 to 30 feet above the ground, showing (*A*) increase in specific gravity with distance from pith for greater part of diameter (*B*) little or no change, and (*C*) decrease. Solid and dotted lines represent specimens taken from opposite sides of the pith.

In the hardwoods, wood of high density may be produced at any stage in the life of the tree, depending on the growth conditions at the particular time the wood is formed *(39)*. In some hickory trees, for instance, wood of high density is found near the pith, and in others farther out in the cross section.

HEARTWOOD AND SAPWOOD

The trunk and principal branches of a tree consist of a central portion called heartwood surrounded by a layer of sapwood.

All wood is formed as sapwood and as the growth of the tree proceeds the inner portion becomes heartwood. In most species the transformation is accompanied by an infiltration of various substances that cause a change in color and in some species by the plugging up of the pores with a frothlike growth, known as "tyloses" *(13)*.

In the many tests which have been made on the various species of wood, no effect upon the mechanical properties of most species due to change from sapwood to heartwood has been found. In general the conditions of growth that prevail when wood is first formed determine

its strength properties and whether heartwood or sapwood is the stronger depends on those conditions. Consequently, in one tree the heartwood may excel and in another of the same species the sapwood. Thus the heartwood of the southern pines and of Douglas fir is not, as has often been supposed to be the case, intrinsically stronger than the sapwood. The sapwood of hickory or ash may be either superior or inferior to the heartwood for handles (*8*). In some instances, however, as shown in the discussion of extractives, heartwood and sapwood do differ essentially in strength properties.

The heartwood of many species is of much darker color than the sapwood. In numerous species, on the other hand, the color difference is nonexistent or very slight. The sapwood of all species is lacking in resistance to decay and rapidly loses its strength if exposed to conditions favoring the growth of decay-producing organisms. The heartwood of some species is very resistant to decay, while that of other species is readily attacked.

Sapwood is more permeable to liquids than heartwood, and hence is desirable in wood that is to be impregnated or treated to increase its resistance to decay, fire, or insect attack.

VARIATION AMONG TREES

In addition to the variation of wood from one part to another of the same tree, there are considerable differences among trees of a species including those that grow side by side. The magnitude of these variations is illustrated by data on redwood. Of 57 virgin-growth trees examined in lots of 4 to 6 from each of 12 different localities throughout the range, the greatest observed difference in average specific gravity between individual trees from a single locality was 25 percent, based on the heaviest tree, whereas considering the entire range the greatest difference between individual trees was only 30 percent. The two trees representing the extremes found in the entire range were from the same county. These data indicate that the growth conditions affecting individual trees within a single site, and perhaps inherent differences in strains or types of trees, are of much greater importance in causing variations in specific gravity than geographical location within the normal range of growth of the species.

Probable variation of random tree from average for species

Property:	Percent
Specific gravity based on volume when green	4
Static bending:	
Fiber stress at proportional limit	9
Modulus of rupture	7
Modulus of elasticity	9
Work to maximum load	15
Impact bending:	
Fiber stress at proportional limit	8
Work to proportional limit	12
Height of drop	13
Compression parallel to grain:	
Fiber stress at proportional limit	12
Crushing strength	7
Compression perpendicular to grain: Fiber stress at proportional limit	14
Hardness:	
End	10
Side	9
Shearing strength parallel to grain	7
Tension perpendicular to grain	12

The preceding tabulation presents an estimate of the probable variation of a random tree from the average for a species, for a number of physical and mechanical properties. The values are general figures derived from a number of species.

LOCALITY OF GROWTH

In considering the causes of variations in properties of wood, it may first be noted that many factors affect the growth of trees. Such features of environment as soil, soil moisture, climatic conditions, and competition for light and food, vary widely within small areas, and are subject to further variation from one period to another during the life of the tree. Their effect is seemingly of greater importance than geographical location within the normal range of a species. This is indicated by the finding of significant differences in strength properties between samples from adjacent areas, among trees grown within a few yards of each other and between the inner and outer portions of the same tree and the observation that samples from widely separated regions may be very similar (*29*). This is illustrated by the discussion of redwood on page 42.

A further example is noted in Sitka spruce. Samples from two localities in Oregon show an average difference of 12 percent in specific gravity and 20 percent or more in modulus of rupture. In contrast, samples from near Ketchikan, Alaska, tested in a green condition, average the same in specific gravity as samples from near Portland, Oreg., and the difference in modulus of rupture was only a few percent. These and similar observations lead to the general conclusion that, in the absence of specific data concerning a given lot of material, average data for the species is a more reliable estimate of the strength properties of that lot than data on samples from adjacent localities or from sites that appear to be the same. However, there may be differences apparent in the grade and quality of wood from different stands, especially old-growth and second-growth stands in which prevalence of defects, seasoning characteristics, and the like, are sufficient in importance to justify marketing preferences.

The whole problem of the effect of region, site, and conditions of stand on wood properties is an exceedingly complicated one, and sufficient data are not available nor has sufficient study been made to attempt a final appraisal.

A few instances of significant differences in the properties of a species grown in different regions have been noted. For example, Douglas fir grows to larger size in the moist region of the Pacific Northwest than in the drier Rocky Mountain States, and the wood from the former region averages somewhat higher in specific gravity and strength properties than the latter. On the other hand, weight for weight, the wood from the two regions has the same strength, and pieces of Douglas fir from the Rocky Mountain region may be selected which are higher in properties than unselected Douglas fir from the Pacific Northwest.

Another significant effect of growth conditions on properties is that resulting from inundation. Some of the hardwoods, notably ash and tupelo gum (*44*) grown in the overflow bottom lands of the lower Mississippi basin develop swelled butts, the wood in which although of rapid growth and relatively good appearance, is low in specific gravity and poor in mechanical properties compared to average mate-

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rial of the species. The characteristics of the wood from these swelled butts are so unlike those of the normal wood of the species that it cannot be satisfactorily employed for the same uses. Wood above this butt swell usually is normal in properties. Hence one utilization problem is the proper classification of such stock according to its properties and potential uses.

RATE OF GROWTH

Rate of growth as indicated by the width of the annual rings is of some assistance in appraising the physical and mechanical properties of wood, but it cannot be regarded as an efficient criterion for selection. Density or specific gravity, as explained on page 36, is a much more reliable criterion of strength. In any species, wood of excellent mechanical properties may vary considerably in rate of growth, but such material will quite consistently be of good density.

Among the ring-porous hardwoods, such as hickory, ash, and the oaks, the production of wood with low specific gravity is caused by some unfavorable condition which interferes with the normal growth of the tree. As a rule, wood of fairly rapid growth put on at any

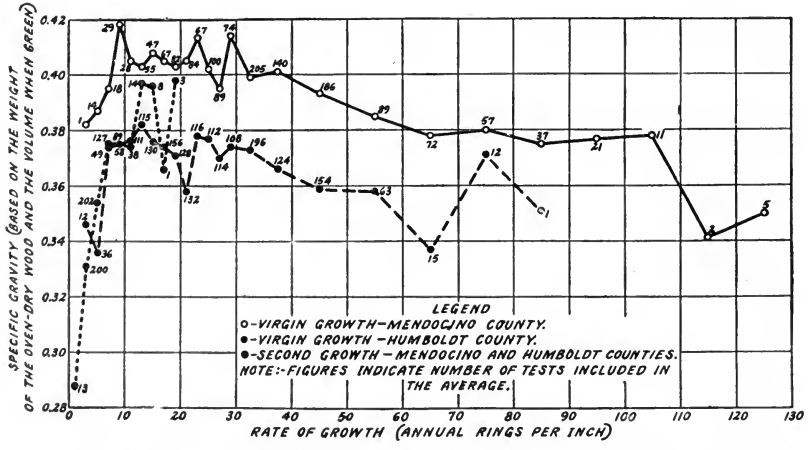

FIGURE 8.—Relation between specific gravity and rate of growth of the heartwood of redwood.

period of the life of the tree, is likely to be excellent in weight and strength. Wood of slow but uniform growth near the center of a tree may also be of high density, but wood of slow growth near the outside of the same tree is sure to be poorer if an interval of faster growth has intervened, or if the outer growth is slower than that about the center (*39*). Hence, in the ring-porous hardwoods fast growth (few rings per inch) is generally indicative of good strength properties, although slow growth does not necessarily indicate weak material. An exception is found in the rapid growth material from swelled butts of swamp-grown trees (p. 40).

Of the diffuse-porous hardwoods studied, sugar maple trees produced dense wood during early age whether their growth was rapid or slow. In some of the yellow poplar trees examined, wood of more rapid growth near the center was lighter in weight than that from the rest of the cross section, while other trees growing on rich alluvial soil

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did not exhibit this difference. Accelerated growth following a period of slow growth resulted in an increase in the specific gravity of the wood, and hence in strength.

Softwood species show a wide range in density and strength at each rate of growth, but usually the strongest material is associated with a normal growth rate. Exceedingly rapid or exceptionally slow growth is most likely to be attended by low density and low mechanical properties. The lighter weight, slow-growth material shrinks and swells less with moisture changes than the heavier material, and usually stays in place better because of its greater freedom from internal stresses, so that it is to be preferred for many uses not primarily involving strength.

Figure 8 illustrates the relations between rate of growth (rings per inch) and specific gravity for redwood (*24*), and figure 9, the relation between rate of growth and modulus of rupture and work to maximum load for hickory.

TIMBER FROM LIVE AND FROM DEAD TREES

Sound wood from trees killed by insects, fungi, wind, or fire is, unless unduly checked, as good for any structural purpose as that from trees that were alive when cut (*20*).

If a tree stands on the stump after its death the sapwood is likely to become decayed or to be severely attacked by wood-boring insects, and in time the heartwood will be similarly affected. Such deterioration occurs also in logs that have not been properly cared for subsequent to being cut from live trees. Because of variations in climatic and local weather conditions and in other factors that affect the rate of deterioration, the length of the period during which timber may stand dead on the stump or may lie in the forest without serious deterioration varies. Tests on wood from trees of one species that had stood as long as 15 years after fire-killing demonstrated that this wood was sound and as strong as wood from live trees. Also logs of some of the more durable species have had thoroughly sound heartwood after lying on the ground in the forest for several decades. On the other hand, decay may cause great loss of strength within a very brief time, both in trees standing dead on the stump and in logs that have been cut from live trees and allowed to lie on the ground. Consequently, the important consideration is not whether the trees from which timber products are cut are alive or dead, but whether the products themselves are free from decay or other defects that would render them unsuitable for use. In considering the utility of timber from a dead tree it is helpful to remember that the heartwood of a living tree is entirely dead, and in the sapwood only a fraction of the cells are alive.

Decay that is not sufficiently advanced to be readily detected may still affect seriously the strength of a piece of wood. For this reason and also because decay is present in timber from dead trees more frequently than in that cut from freshly felled live trees, timber from dead trees needs more careful inspection. Specifications for some timber products, notably poles and piling, often require that only live trees be used. This requirement is difficult to enforce unless inspection is made in the forest, because wood cut from dead trees before weathering, seasoning, discoloration, decay, insect attack, or similar change has occurred cannot ordinarily be distinguished from wood

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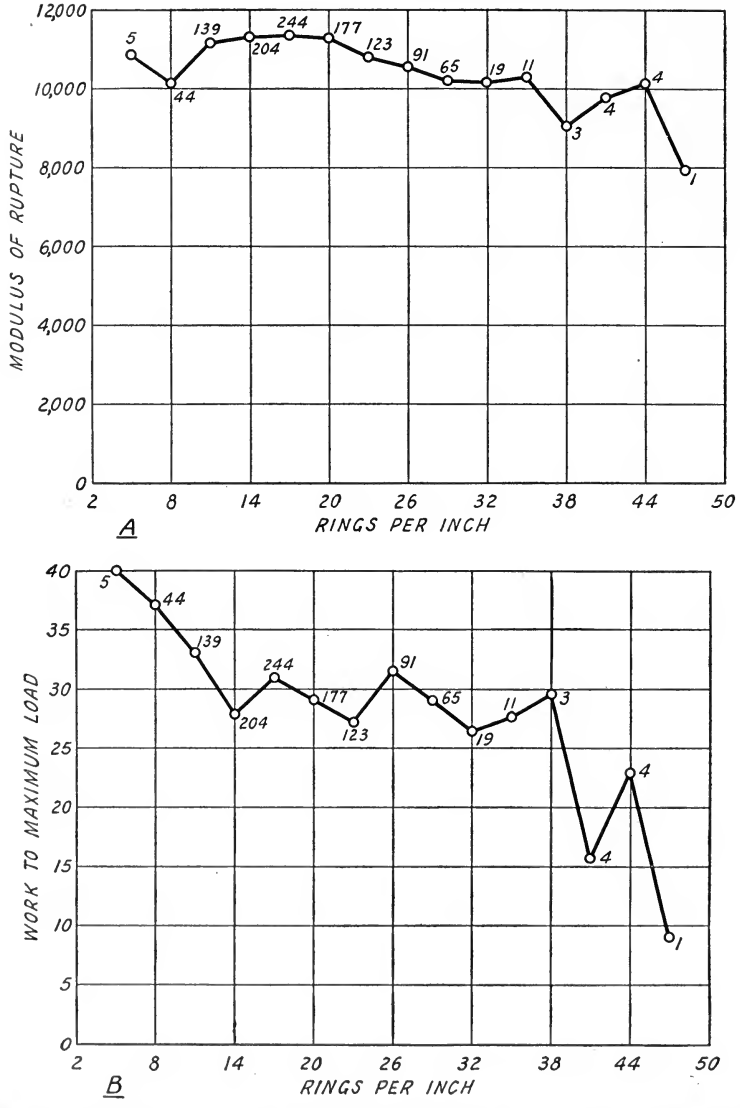

FIGURE 9.—Relation between the rate of growth and modulus of rupture (*A*) and also work to maximum load for green hickory (*B*). Figures indicate number of tests included in the average.

taken from live trees. Many specifications omit the live-tree requirement, depending entirely on inspection to determine the suitability of timber for use.

EFFECT OF RESIN AND OF TURPENTINING

Resin is formed in some of the conifers, especially the southern pines. Amounts up to 6 percent of the weight of the dry wood are common, and pieces with a resin content up to 50 percent are sometimes found.

Tests at the Forest Products Laboratory on southern yellow pine indicate that resin will slightly increase some strength properties but the effect is too small to be of any practical significance (*10*). An excessive amount of resin is sometimes associated with an injury such as a compression failure that may have greatly reduced the strength.

Longleaf and slash pine trees are frequently "tapped" for turpentine. The results of a special investigation, involving mechanical tests, and physical and chemical analyses of the wood of turpentined and unturpentined trees from the same locality (*10*), show that (1) turpentined timber is as strong as unturpentined if of the same weight (table 15); (2) the weight and shrinkage of the wood is not affected by turpentining; and (3) except in parts adjacent to the "faces" where there may be a concentration of resin, turpentined trees contain practically neither more nor less resin than unturpentined trees, the exudation of resin occurring only from the sapwood, and therefore the resin content of the heartwood is not affected by the turpentining process.

TABLE 15.—*Effect of turpentining on the strength of longleaf pine*

Item	Tests	Relative specific gravity of test pieces	Modulus of rupture	Maximum crushing strength (parallel to grain)
	Number		*Lb. per sq. in.*	*Lb. per sq. in.*
Unboxed (not turpentined) trees	400	1.00	12,358	7,166
Boxed (turpentined) and recently abandoned	390	1.07	12,961	7,813
Boxed (turpentined) and abandoned 5 years	535	1.03	12,586	7,575

EXTRACTIVES AS RELATED TO STRENGTH

Extractives are constituents that dissolve when a piece of wood is placed in a solvent that has little or no effect on the wood substance. They are referred to as cold-water, hot-water, or alcohol-soluble extractives, depending on the solvent used. Extractives are found in the heartwood of many species and are especially abundant in redwood, western red cedar, and black locust. These species are also relatively high in certain strength properties for the amount of wood substance they contain, particularly when unseasoned, and tests have shown that the presence of extractives is probably accountable. The extent to which extractives affect the strength is apparently dependent upon the amount and nature of the extractives, the species of wood, the moisture condition of the piece, and the mechanical property under consideration. Of the properties examined, maximum crushing strength in compression parallel to the grain showed the greatest increase as the result of the infiltration of extractives accompanying the change of

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sapwood into heartwood, and shock resistance the least, with modulus of rupture intermediate. In fact, under some conditions shock resistance appears to be actually lowered by extractives. That extractives may affect different species differently is indicated by the fact that they appear to affect the strength of western red cedar less than the strength of black locust, although black locust has a smaller percentage of extractives (*23*). Difference in the character of the extractives is probably also a factor in this connection.

TIME OR SEASON OF CUTTING

The time or season of cutting is sometimes thought to affect the properties and durability of wood, but so far as is known it actually has very little direct effect on the characteristics of the wood itself. The method of handling after cutting, however, may be very important. During the summer, for instance, seasoning proceeds more rapidly and is more apt to produce checking than in the winter. Insects, stains, and decay-producing fungi are more vigorous in the summer and the freshly-cut wood is most subject to attack at this time. Winter cutting, therefore, has the advantage that more favorable seasoning conditions and greater freedom from stains, molds, decay, and insects simplify the problem of caring for the timber before conversion. There is but little difference in the moisture content of green wood in winter and in summer.

MOISTURE AS RELATED TO STRENGTH

Wood in the green state contains considerable moisture varying from about 30 to 40 percent (based on the weight of the dry wood) in the heartwood of some of the pines to over 200 percent in some other species. Part of this moisture is held absorbed by the cell walls and part is held within the cell cavities as water is held in a container (*15, 47, 60*). As wood dries, the cell walls do not give off moisture until the adjacent cavities are empty. The condition in which the cell walls are fully saturated and the cell cavities empty is known as the "fiber-saturation point." It varies from 25 to 35 percent moisture content.

Increase in strength begins when the cell walls begin to lose moisture; that is, after the wood is dried to below the fiber-saturation point. From this point on most strength properties increase rapidly as drying progresses. This increased strength of dry over green wood of the same dimensions is due to two causes: (1) Actual strengthening and stiffening of the cell walls as they dry out, and (2) increase in the compactness or the amount of wood substance in a given volume because of the shrinkage that accompanies drying below the fiber-saturation point.

Drying wood down to 5-percent moisture may add from about 2½ to 20 percent to its density, while in small pieces its end-crushing strength, and bending strength, may easily be doubled and in some woods tripled. Thus, the first of the two factors mentioned is the one chiefly responsible for the increase in strength.

The increase in strength with seasoning is much greater in small clear specimens of wood than in large timbers containing defects. In the latter the increase in strength is to a large extent offset by the influence of defects that develop in seasoning.

The various strength properties are not equally affected by changes in moisture content. Whereas some properties, such as crushing strength and bending strength increase greatly with decrease in moisture, others, such as stiffness, change only moderately, and still

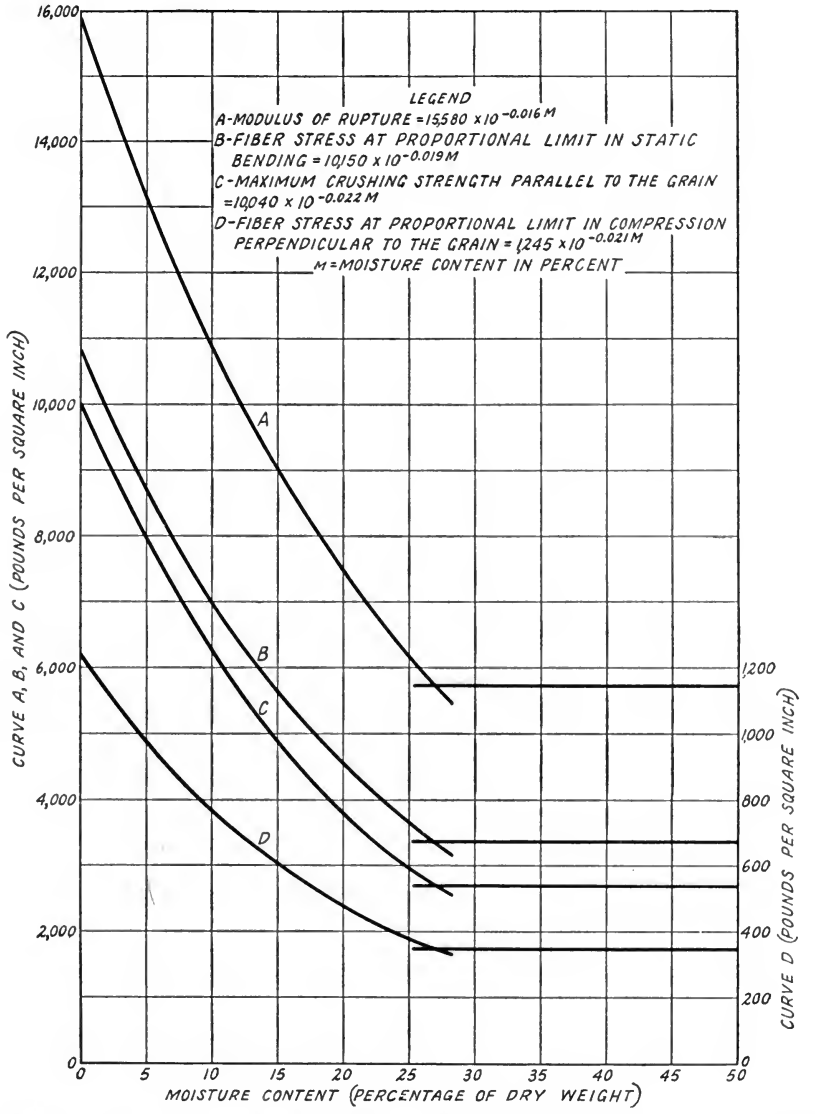

FIGURE 10.—The relation between mechanical properties and the moisture content of small clear specimens of Sitka spruce.

others, such as shock resistance, may even show a slight decrease. This last effect is due to the fact that drier wood does not bend so far as green wood before failure, although it will sustain a greater load, and because shock resistance or toughness is dependent upon both strength and pliability.

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The following tabulation shows the average variation of the strength properties of wood with change in moisture content, and figure 10 shows graphically the effect of moisture on certain strength properties of Sitka spruce.

Average increase (or decrease) in value effected by lowering (or raising) the moisture content 1 percent

Property:	Percent
Static bending:	
Fiber stress at proportional limit	5
Modulus of rupture, or cross-breaking strength	4
Modulus of elasticity or stiffness	2
Work to proportional limit	8
Work to maximum load or shock-resisting ability	½
Impact bending:	
Fiber stress at proportional limit	3
Work to proportional limit	4
Height of drop of hammer causing complete failure	−½
Compression parallel to grain:	
Fiber stress at proportional limit	5
Maximum crushing strength	6
Compression perpendicular to grain:	
Fiber stress at proportional limit	5½
Hardness, end grain	4
Hardness, side grain	2½
Shearing strength parallel to grain	3
Tension perpendicular to grain	1½

METHODS OF MOISTURE-STRENGTH ADJUSTMENT

It is often desirable to adjust strength values for wood at one moisture content to what they would be under some other condition. This can be done quite accurately when the data apply to small clear specimens which are quite uniformly dried so that the moisture content is approximately the same at all points of the cross section.

Three general methods, differing materially in their accuracy, and in simplicity and facility of application, may be used for moisture-strength adjustments. These are referred to as the (1) approximate method, (2) the equation method, and (3) the graphical method.

APPROXIMATE METHOD

The approximate method of moisture-strength adjustment consists simply in an application of the percentage figures of the tabulation above for the property under consideration, regardless of species. For example, if the maximum crushing strength of Sitka spruce at 12-percent moisture content is 5,610 pounds per square inch, what is the approximate value at 10-percent moisture? From the tabulation it may be noted that the average change in maximum crushing strength for 1-percent change in moisture is 6 percent. For 2-percent change in moisture content (12-percent moisture to 10-percent moisture) the average expected change in maximum crushing strength would consequently be 12 percent. Since this property increases with decrease in moisture content, the approximate increase in strength is 12 percent of 5,610=673, and the approximate maximum crushing strength at 10-percent moisture is 5,610+673=6,283 pounds per square inch.

This is the least accurate of the several methods described, and is useful only for making rough approximations. For comparison it may be noted that application of the equation method to the foregoing example gives a value of 6,194 pounds per square inch.

EQUATION METHOD

Studies at the Forest Products Laboratory (*60*) have led to the derivation of a formula for strength adjustment, the numerical solution of which affords more accurate estimates than any other method. This formula, known as the exponential formula is based on the fact that for any one species and strength property, moisture-content values within certain limits and the logarithms of corresponding strength values have been found to conform closely to a straight-line relationship.

The formula may be written

$$\text{Log } S_D = \log S_C + (C-D)\,\frac{\log (S_B \div S_A)}{A-B}$$

where A, B, C, and D, are values of moisture content and S_A, S_B, S_C, and S_D are corresponding strength values; S_C is the strength value from tests made at moisture content C and S_D is this strength value adjusted to moisture content D. The expression

$$\frac{\log (S_B \div S_A)}{A-B}$$

which is equivalent to

$$\frac{\log S_B - \log S_A}{A-B}$$

measures the change in strength property caused by a change of 1 percent in the moisture content. Required for evaluation of this expression are strength values S_A and S_B found from tests made at two different moisture contents A and B on matched specimens; that is, specimens that can be assumed to be alike except for the single factor of moisture content, such as specimens from closely adjacent positions within the same annual growth layers.

When in any instance a strength value is that for green material, the corresponding moisture content to be used for the species under consideration is listed in the following tabulation:

Species[9]	*Moisture content* *Percent*
Ash, white	24
Birch, yellow	27
Chestnut	24
Douglas fir	24
Hemlock, western	28
Larch, western	28
Pine:	
Loblolly	21
Longleaf	21
Norway	24
Redwood	21
Spruce:	
Red	27
Sitka	27
Tamarack	24

[9] The exact value has been determined only for the species listed here. For other species the value of 24 percent may be assumed to apply.

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Three types of moisture-strength adjustment differing with respect to the source of the data for evaluating the expression

$$\frac{\log\ (S_B \div S_A)}{A-B}$$

are defined and illustrated in the following paragraphs:

TYPE 1. From tests on matched groups of material at two different moisture-content values, a strength value corresponding to a third value of moisture content is computed, the data for evaluating the expression

$$\frac{\log\ (S_B \div S_A)}{A-B}$$

being supplied by the tests on the material under consideration.

Example: The average maximum crushing strength of Sitka spruce as listed in table 1 is 2,670 pounds per square inch for green material and 5,610 pounds per square inch for material at 12 percent moisture. Compute the maximum crushing strength corresponding to a moisture content of 14 percent.

S_A=2,670 from table 1, and A for green material is 27.

S_B=5,610, B=12. C may be taken either as 27 or 12 with corresponding choice of S_C; that is, either the value for green material or that for material at 12-percent moisture may be adjusted to 14-percent moisture content.

D=14.

Taking C=12, and S_C=5,610.

$$\text{Log } S_{14}=\log 5{,}610+(12-14)\frac{\log\ (5{,}610\div 2{,}670)}{27-12}$$

$$=3.7490-2\times\frac{0.3224}{15}$$

$$=3.7490-0.0430=3.7060$$

Then S_{14}=antilog 3.7060=5,082.

or

Taking C=27 and S_C=2,670

$$\text{Log } S_{14}=\log 2{,}670+(27-14)\frac{\log\ (5{,}610\div 2{,}670)}{27-12}$$

$$=3.4265+13\times\frac{0.3224}{15}$$

$$=3.4265+0.2794=3.7059$$

Then S_{14}=antilog 3.7059=5,082 as before, and the maximum crushing strength of Sitka spruce at 14-percent moisture content, as obtained by adjusting to this moisture content the average values given in table 1, is 5,082 pounds per square inch.

TYPE 2. A strength value obtained at one moisture content is adjusted to a second value of moisture content, the data for evaluating the expression

$$\frac{\log (S_B \div S_A)}{A-B}$$

as found in other tests on the same species being assumed to apply.

Example: A specimen of longleaf pine at 9.8-percent moisture content was found from test to have a modulus of rupture of 13,500 pounds per square inch. Estimate the value of modulus of rupture that would have resulted had the test been made at a moisture content of 12 percent.

Values of modulus of rupture on matched specimens of longleaf pine are given in table 1 as 8,700, which is equal to S_A, and 14,700, which is equal to S_B, pounds per square inch for the green and 12-percent moisture conditions, respectively. A, from the tabulation (p. 51) $=21$, $B=12$, $C=9.8$, and $D=12$.

Then substituting in the formula

$$\text{Log } S_{12}=\log 13{,}500+(9.8-12)\frac{\log (14{,}700 \div 8{,}700)}{21-12}$$

$$=4.1303-2.2\times\frac{0.2278}{9}$$

$$=4.1365-0.0557=4.0746$$

S_{12}=antilog 4.0746=11,874

and the modulus of rupture at 12-percent moisture as estimated from the value determined at 9.8-percent moisture is 11,874 pounds per square inch.

TYPE 3. As in type 2, except that the data for evaluating the expression

$$\frac{\log (S_B \div S_A)}{A-B}$$

for the same species not being known an average value as computed from tests of other species is assumed to apply.

Example: The modulus of rupture of a sample of a hardwood species tested at 9-percent moisture content was 11,700 pounds per square inch. Estimate the value at 12-percent moisture. Here $S_G=11{,}700$, $C=9$, and $D=12$. No values of S_A and S_B for the same species being available, it is assumed that the strength-moisture relationship for this hardwood is similar to that for hardwood species in general and 1.59, the value of $\frac{S_{12}}{S_G}$ as given for modulus of rupture of hardwood species in table 16, is used for $\frac{S_A}{S_B}$. $A=12$ and for B the value of 24 from the tabulation on page 51 is taken. Substituting in the formula:

$$\text{Log } S_{12}=\log 11{,}700+(9-12)\frac{\log 1.59}{24-12}$$

$$=4.0682-3\times\frac{0.2014}{12}$$

$$=4.0682-0.0503=4.0179$$

TABLE 16.—*Average strength ratios* $\left(\frac{S_{12}}{S_g}\right)$ *for species in drying from a green condition to 12-percent moisture content*

Property	Hardwoods (113 species)	Softwoods (54 species)
Static bending:		
Fiber stress at proportional limit	1.80	1.81
Modulus of rupture	1.59	1.61
Modulus of elasticity	1.31	1.28
Work to proportional limit	2.49	2.56
Work to maximum load	1.05	1.13
Impact bending:		
Fiber stress at proportional limit	1.44	1.39
Work to proportional limit	1.68	1.59
Height of drop causing complete failure	.89	1.03
Compression parallel to grain:		
Fiber stress at proportional limit	1.74	1.86
Maximum crushing strength	1.95	1.97
Compression perpendicular to grain: Fiber stress at proportional limit	1.84	1.96
Hardness:		
End	1.55	1.67
Side	1.33	1.40
Shear parallel to the grain: Maximum shearing strength	1.43	1.37
Tension perpendicular to grain: Maximum tensile strength	1.20	1.23

$$S_{12}=\text{antilog } 4.0179=10{,}400$$

Obviously, adjustments of type 1 are most and those of type 3 least accurate. The inaccuracy in types 2 and 3 is due to the assumed values of the expression

$$\frac{\log\ (S_B \div S_A)}{A-B}$$

not being definitely applicable.

In types 2 and 3 the accuracy of the computed or estimated value decreases with increase in moisture difference for which adjustment is made.

GRAPHICAL METHOD

The graphical method consists of using a chart (fig. 11) for the solution of the formula described under the equation method, thus avoiding the use of logarithms as required in the arithmetical calculation. This method is, therefore, simpler than the equation method, but due to the personal equation in reading the chart and the small scale of the chart, the adjustment is less accurate.

The procedure in the use of the chart is as follows:

1. First determine K, the ratio of the strength when dry to the strength when green for the strength property and species under consideration. This ratio should be determined from one of the three following sources, with preference in the order named:

(*a*) From the tests of matched green and dry material for which the adjustment is to be made.

(*b*) From the data for green and dry material of table 1.

(*c*) From the ratios of table 16.

2. Determine the difference in moisture between the value to be used for green material (table 1) and the moisture content of the dry material on which the preceding dry to green strength ratio is based. (For all species listed in table 1 the moisture content of the dry material is 12 percent.

3. Determine the difference between the moisture content of the material at test and the moisture content to which adjustment is to

be made. This difference represents the range in moisture over which the adjustment is to be made.

4. Locate on the chart a point corresponding to the difference in moisture content as determined under 2 and the ratio K as determined under 1. From the line joining this point with the lower

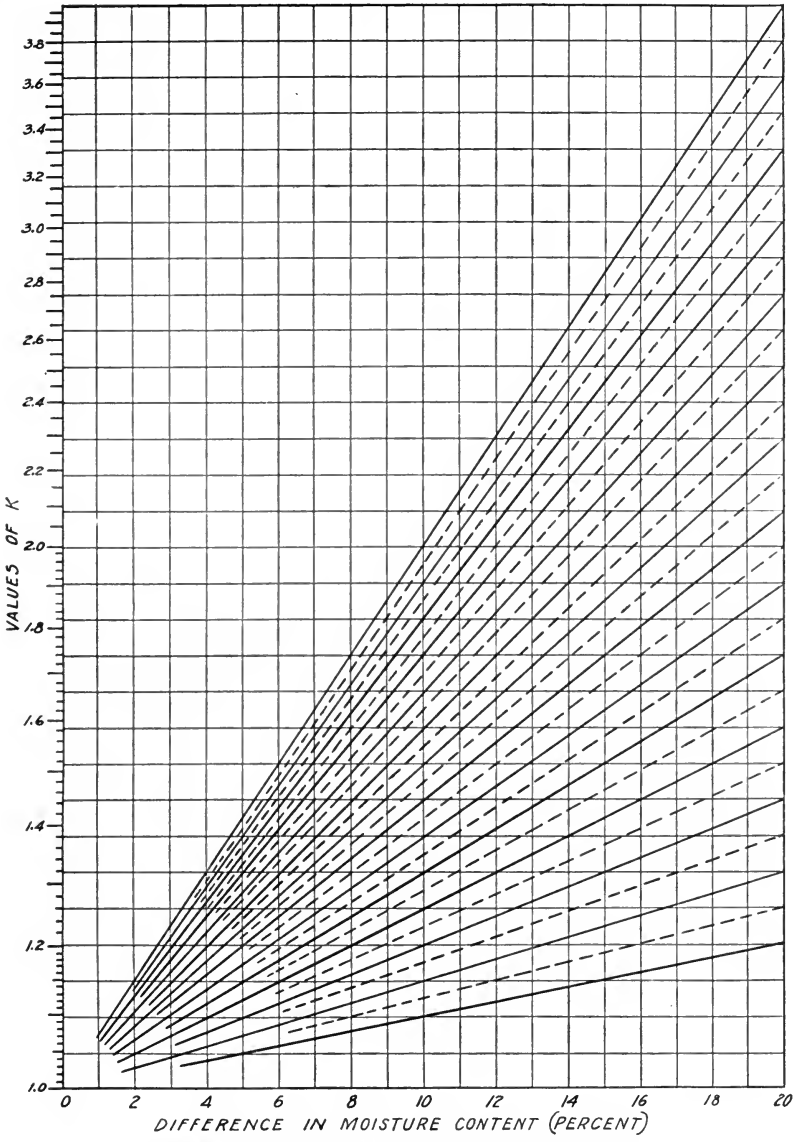

FIGURE 11.—Chart for making strength-moisture adjustments.

left-hand corner of the chart the ratio corresponding to any difference in moisture content can be found.

5. Locate on this line, the point that corresponds to the difference in the moisture content as determined under 3, and read the corresponding new strength ratio K on the left-hand scale.

6. (*a*) If the adjustment is being made to a lower moisture content than that at which the tests were made, multiply the strength at test by the new ratio (as obtained in 5 above) to get the adjusted strength value.

(*b*) If the adjustment is being made to a higher moisture content than that at which the tests were made, divide the strength at test by the new ratio (as obtained in 5 above) to get the adjusted strength value.

Example 1. Tests of matched specimens of Douglas fir gave values of maximum crushing strength of 3,940 and 10,680 pounds per square inch, respectively, for green wood and wood at 6.2-percent moisture content. What is the strength at 12-percent moisture content?

1. The ratio $K=\frac{10,680}{3,940}=2.71$.

2. The difference between the moisture content to be used for green material (tabulation on p. 51) and that at test is $24-6.2=17.8$ which is the difference in moisture content to which the ratio 2.71 applies.

3. The difference between the moisture content of the dry material at test and the moisture content to which adjustment is desired is $12-6.2=5.8$.

4. Starting with the ratio 2.71 on the left-hand margin of figure 11, and following horizontally to the vertical representing the 17.8-percent moisture difference, locate a point.

5. Following the converging line on which this point is located to its intersection with a vertical corresponding to the moisture difference of 5.8 (step 3), and thence horizontally to the left-hand margin, a new ratio K of 1.38 is found.

6. The maximum crushing strength at 12 percent moisture is $\frac{10,680}{1.38}=7,740$ pounds per square inch. The moisture content of 12 percent to which adjustment is made is higher than the moisture content at test. Consequently the strength value at test is divided by the ratio.

Example 2. The modulus of rupture of a sample of hardwood species tested at 13-percent moisture content was 10,030 pounds per square inch. What is the estimated value at 9-percent moisture?

1. Since data on matched green and dry material are not available, the average ratio of strength when dry (12-percent moisture content) to that when green for a hardwood is taken from table 16, and is 1.59.

2. From the tabulation on page 51, the moisture content to be used for green material is assumed to be 24-percent moisture content. The ratio of 1.59 applies to material at 12-percent moisture content. The moisture difference is, therefore, $24-12=12$-percent moisture content.

3. The differences between the moisture content of the sample at test and the moisture to which adjustment is desired is $13-9=4$ percent.

4. Starting with the ratio 1.59 on the left-hand margin of figure 11, and following horizontally to the vertical representing 12-percent moisture difference, locate a point.

5. Following the converging line through this point to its intersection with the vertical corresponding to the moisture difference of 4

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percent (step 3), and thence horizontally to the left-hand margin, the ratio K of 1.165 is found.

6. The modulus of rupture at 9-percent moisture content is $10,030 \times 1.165 = 11,680$ pounds per square inch. In this instance the moisture content of 9 percent to which adjustment is made is lower than the moisture content at test and the strength value at test is multiplied by the ratio K.

LIMITATIONS TO MOISTURE-STRENGTH ADJUSTMENTS

When the strength data are from tests on material in which the moisture is not uniformly distributed in the cross section, moisture-strength adjustments on the basis of the methods just outlined cannot be considered as reliable, and no acceptable general method for the adjustment of such data is available.

COMPARATIVE STRENGTH OF AIR-DRIED AND KILN-DRIED WOOD

Some wood users contend that kiln-dried wood is brash and not equal in strength to wood that is air-dried. Others advance figures purporting to show that kiln-dried wood is much stronger than air-dried. However, comparative strength tests, made by the Forest Products Laboratory on kiln-dried and air-dried specimens of 28 common species of wood, show that good kiln drying and good air drying have the same effect upon the strength of wood but that severe conditions in the kiln will lower most of the strength properties (*56*).

The belief that kiln drying produces stronger wood than air drying is usually the result of failure to consider differences in moisture content. The moisture content of wood on leaving the kiln is generally from 2 to 6 percent lower than that of thoroughly air-dried stock. Since wood rapidly increases in most strength properties with loss of moisture, higher strength values may be obtained from kiln-dried than from air-dried wood. Such a difference in strength is not permanent, since in use a piece of wood will come to practically the same moisture condition whether it is kiln-dried or air-dried.

It must be emphasized that the appearance of wood is not a reliable criterion of the effect the drying process may have upon its strength. The strength properties may be seriously injured without visible damage to the wood. Also, it has been found that the same kiln-drying process cannot be applied with equal success to all species. To insure kiln-dried material of the highest strength, a knowledge of the correct kiln conditions to use with stock of a given species, grade, and thickness, and a record showing that no more severe treatment has been employed, are necessary.

TEMPERATURE AS RELATED TO STRENGTH

The moisture content of wood determines to a large extent how it is affected by temperature.

Lowering the temperature of wet or green wood decidedly increases its stiffness and its strength in compression parallel to grain. Freezing temperatures have resulted in increases of from 5 to 25 percent as compared to values at normal room temperature, the results varying with the strength property considered, the species, and the moisture condition (*12*, *47*). Such effects are much less pronounced in wood

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whose moisture content is below the fiber-saturation point and become comparatively small at very low moisture content values.

Tests in compression parallel to grain have shown values for green wood at temperatures near the boiling point about one-fifth as great as at normal room temperature. Including both moisture and temperature effects a tenfold difference in maximum crushing strength has been observed between specimens tested immediately after soaking in hot water and other matched specimens that were tested after cooling subsequent to over drying to expel all moisture. This illustrates the importance of establishing comparable conditions of moisture and temperature when making comparisons involving strength.

Aside from the current or immediate effects of temperature as just cited, tests have shown that heating to or above the boiling point for several hours or to more moderate temperatures, such as are used in kiln drying, for longer periods may permanently lower the strength properties as compared to unheated wood at the same moisture content. The effect on the strength at some lower moisture content is somewhat less than on the strength of wood in the green or wet condition. The amount of this lowering apparently depends on a large number of variables including species, size, and moisture content of the material when heated, the temperature, and the duration of the heating period (*22*, *42*, *59*).

Steaming or boiling of wood for brief periods is used to make it pliable and prepare it for bending to curved form. Such preparation makes it possible to bend the wood to curvatures otherwise unattainable. The heating is usually for comparatively brief periods and probably has little permanent effect on the strength.

EFFECT OF PRESERVATIVE TREATMENT ON STRENGTH

Coal-tar creosote, water-gas tar, wood-tar creosote, creosote-tar mixtures, and creosote-petroleum mixtures are practically inert to wood and have no chemical influence upon it that would affect its strength (*6*). The 2- to 5-percent solutions of zinc chloride commonly used in preservative treatment apparently have no important effect.

Although wood preservatives are not harmful in themselves, the treatment used in injecting them into the wood may result in considerable loss of strength to the wood. Green wood conditioned for the injection of preservatives by steaming or by boiling under vacuum may be seriously reduced in strength if extreme temperatures or heating periods are employed. Consequently, care should be used to keep the temperature as low and the duration of the treatment as short as is consistent with satisfactory absorption and penetration of the preservative (*59*). A gage pressure of 20 pounds (259° F.) is sufficiently high for steam conditioning. No advantage is known to result from higher pressures, and the resulting higher temperatures are much more likely to damage the wood. The maximum temperature employed in the boiling-under-vacuum process is usually less than 210°.

The use of pressures greater than 175 pounds in injecting preservatives into wood that is soft from long heating is likely to cause severe end checking and collapse. Considerably higher pressures can be used if the wood has been heated for a short time only, or not at all. Woods of low density are more subject to injury from high pressures than woods of high density.

STRENGTH AS AFFECTED BY RATE AND METHOD OF LOADING

DURATION OF STRESS

The duration of stress or the time during which a load or force acts on a beam or other wooden member has an important bearing on the use of the timber, and on the adaptation of results of tests to the design of different kinds of structures or members. For instance, when an airplane traveling at high speed suddenly changes its course as in flattening out following a dive, wooden members may without damage be subjected for a few seconds to forces which would cause complete failure if applied for a longer time. In impact-bending tests, where the load is suddenly applied and is maintained for but a fraction of a second, a stick will resist a force more than double that required to produce failure in a standard static-bending test. On the other hand, beams under continuous loading for years, as in warehouse floors, will fail at loads one-half to three-fourths as great as would be required to produce failure in the standard static bending test where the maximum load is reached in a few minutes (*5*, *27*, *31*, *49*).

From the foregoing it is clear that tests made under widely different conditions of loading are not comparable, and that the allowable stress in a wooden beam must be determined in accordance with the loading to which it will be subjected in service. The rapidity with which the load is applied and the duration of the stress are material factors in the result.

Figure 12 presents an interpretation of some data on the influence of rate of loading from tests of small clear specimens. A tenfold increase or decrease in the rate of loading produces approximately a 10-percent increase or decrease, respectively, in bending strength.

In timber testing, the allowable tolerance in rate of loading is limited to ±25 percent of the required rate in order to keep the variation in test results from this cause within about 1 percent (*48*).

FATIGUE

Some tests have been carried on both in the United States and in Europe to determine the effect of repeated stress and vibration although no extended and thorough or complete investigation has been made (*30*).

In tests made at the Forest Products Laboratory on beams of circular cross section, rotated so that the outer fibers were stressed in compression and tension alternately at each revolution, the fatigue limit was found to be about one-third of the modulus of rupture as determined in static tests, on beams having square cross sections. Sometimes the fatigue limit of wooden beams with circular cross section is expressed as a ratio to the static modulus of rupture of beams also of circular cross section. Expressed in this way the ratio is less than one-third, since a beam of circular section has a form factor of 1.18. These tests involved over 300,000 stress cycles (table 17).

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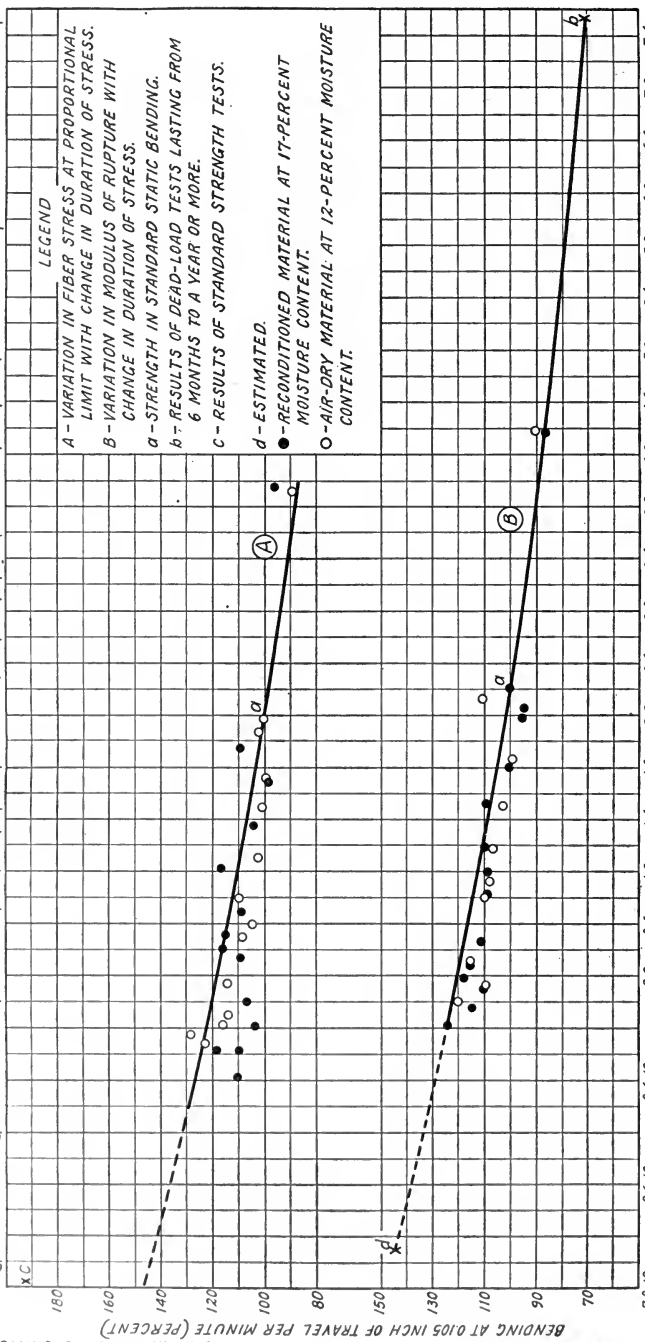

FIGURE 12.—The relation between fiber stress at proportional limit in static bending and modulus of rupture of Sitka spruce, and duration of stress. Each point is the average of the results of from 5 to 10 tests. Duration of stress is the total time between application of load and reaching the proportional limit or the maximum load.

TABLE 17.—*Results of static tests and fatigue rotating beam tests of wood*

Kind of wood	Moisture content	Specific gravity [1]	Static modulus of rupture for specimens of circular cross section	Estimated endurance limit (rotating beam test specimens of circular cross section)	Ratio of endurance limit to modulus of rupture of beams of circular cross section	Ratio of endurance limit to modulus of rupture of beams of square cross section [2]
	Percent		*Lb. per sq. in.*	*Cycles*		
Sitka spruce	13.8	0.38	12,100	3,200	0.27	0.32
Southern white oak	82.4	.58	10,600	3,200	.30	.35
Douglas fir	14.3	.50	15,000	4,000	.27	.32
Do	23.8	.52	12,800	3,900	.31	.37

[1] Specific gravity, oven dry, based on volume at test.
[2] Calculated on basis that form factor of beam of circular cross section is 1.16.

Studies made on cantilever beams having an enlarged cross section at the point of support demonstrated that the fatigue limit varied greatly depending on whether the change of cross section was abrupt or gradual.

With even what is normally considered a generous fillet the fatigue limit is lowered markedly. This effect, together with the influence of form factors, has led some investigators erroneously to place the fatigue limit for wood as low as one-sixth of the static modulus of rupture.

Tests made at the Forest Products Laboratory on tapered specimens of a form to obviate changes in cross section that would influence failure show that, for a stress just slightly greater than the fatigue limit, failure occurs at not more than 2,000,000 load reversals and in some species at less than 1,000,000 reversals. Tests at stresses only slightly less than the fatigue limit showed no failure after reversals ranging in number from 14,000,000 to 125,000,000.

Other tests on Sitka spruce in which specimens of rectangular cross section were vibrated through approximately 5,000,000 cycles indicate that the modulus of elasticity is not greatly affected by vibration. No effect on fiber stress at proportional limit and modulus of rupture could be detected from these tests, the values being about the same for specimens which had and which had not been vibrated. The tests indicate that the same stress prevails at the fatigue limit with vibrated specimens of rectangular cross section as with rotated specimens of circular cross section.

Further studies to obtain more specific information on the effects of vibration and fatigue, particularly when subjected to a large number of stress cycles, and to determine the variation of these properties with different species are needed.

EFFECT OF TIME OR LENGTH OF SERVICE ON THE STRENGTH OF WOOD

It is sometimes assumed that wood is perishable and is suitable only for use in temporary structures. Although wood, like other materials, is subject to attack by destructive agents, there is ample historical evidence of its permanence when protected from attack by such agencies as fungi, insects, marine borers, and rodents.

So far as is known the lignin and cellulose which constitute the wood substance are not subject to chemical change with time when

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wood is adequately protected from the elements and other destructive agencies, although the color of wood may be slightly changed by long-continued exposure to air. Possibly this change of color results from oxidation of substances that are not parts of the wood substance.

The effect of time cannot be appraised accurately by tests of wood from old structures since the original strength of the material is unknown. The evidence from such tests as are on record is that no significant loss of strength has occurred in the absence of the destructive agencies enumerated (*1*, *2*, *14*).

The shrinkage that occurs in the drying of wood induces internal stresses. In time, equalization of differentials of moisture content combined with the action of wood as a plastic material relieves such stresses. This effect would tend to increase the resistance to external forces but its effect is probably not great enough to be significant in most uses of wood.

A recent survey has shown that literally hundreds of bridges made entirely or partly of wood have served satisfactorily and with but little attention for long periods. Many that are more than a century old are still in service. Others have given way, while still in good condition, to the demands for greater width of roadway and higher load capacity than that for which they were built (*11*).

SIZE OF PIECE AS RELATED TO STRENGTH

It is well known that the size and form of a timber have a definite bearing on its load-carrying ability for different purposes, but the manner in which the load-carrying ability and stiffness vary with dimensions is not so generally understood.

SIZE OF COLUMNS OR COMPRESSION MEMBERS

In a short column, that is, a column whose ratio of length to least dimension is 11 to 1 or less, the end load that can be carried varies simply with the area of the cross section of the piece, other factors being equal. However, with a long column, one whose length exceeds about 20 times its least dimension, the end load that can be supported (with a given "end condition") varies not as the cross-sectional area, but directly as the greater dimension of the cross section, directly as the cube of the lesser, and inversely as the square of the length. Columns are usually either square or round. Hence the load that can be carried by a long column of square or circular cross section varies directly as the fourth power of the side of the square or diameter of circle, and inversely as the square of the length. The load that can be supported by columns of intermediate length is intermediate between that for the short and long column (*32*).

SIZE OF BEAMS

The load that a beam of rectangular cross section can carry, other factors being equal, varies directly as the width, directly as the square of the depth, and inversely as the span. The deflection for a given load varies inversely as the width, inversely as the cube of the depth, and directly as the cube of the span.

A few numerical examples will serve to illustrate these relations. Let it be assumed that a beam 1⅝ by 7½ inches (nominal 2 by 8) is used on edge on a 12-foot span.

EFFECT OF WIDTH

If the width of beam were increased from 1⅝ to 3⅝ inches (nominal 4-inch width) a total load about two and one-fourth times as large ($3\frac{5}{8} \div 1\frac{5}{8} = 2.23$) could be carried, and the deflection for a given load would be about 45 percent as great

$$\left(\frac{1}{3\frac{5}{8}} \div \frac{1}{1\frac{5}{8}} = 0.448\right)$$

EFFECT OF DEPTH

If the depth were increased from 7½ to 9½ inches (nominal 10-inch depth) a total load 1.6 times as large, $(9\frac{1}{2})^2 \div (7\frac{1}{2})^2 = 1.60$, could be carried, and the deflection for a given load would be about 49 percent as great

$$\left(\frac{1}{(9\frac{1}{2})^3} \div \frac{1}{(7\frac{1}{2})^3} = 0.492\right)$$

EFFECT OF LENGTH

If the span were increased from 12 to 15 feet a total load 80 percent as large $\left(\frac{1}{15} \div \frac{1}{12} = 0.80\right)$ could be carried, and the deflection for a given load would be nearly twice as great ($15^3 \div 12^3 = 1.95$).

The preceding relations are those expressed by the usually accepted engineering formulas and are based on assumptions that are more or less inaccurate under certain conditions. Their use, however, has been long established and they may be regarded as the best general basis for calculation.

Since strength and stiffness are dependent on the form and size of piece as well as on the inherent strength of the wood, it is usually possible to compensate for the lower strength of the weaker species by increasing the size of members in accordance with engineering principles.

FORM OF CROSS SECTION AS RELATED TO STRENGTH OF WOODEN BEAMS

Calculations by the commonly accepted engineering formulas as previously illustrated are sufficiently accurate for use in the design of members of rectangular cross section for common structural purposes. Experiments have demonstrated, however, that beams may carry more or less load, depending on the form of the cross section, than would be calculated from the general beam formula, using the modulus-of-rupture value based on specimens 2 by 2 inches in cross section as given in table 1. Hence, when members of other than rectangular section are used, or when maximum accuracy is essential, as in the design of aircraft parts, modification of these formulas is necessary (*36*).

Tests have shown that a beam of given cross-sectional area carries the same load regardless of whether the cross section is circular, square, or diamond shape (square with diagonal in the direction of load). This is true both of loads at proportional limit and of maximum load. The corresponding stresses computed from the usual formula are 18 percent higher for the circular and 41 percent higher

for the diamond-shaped beam than for the square. Thus the circular and diamond-shaped sections may be said to have form factors of 1.18 and 1.41, respectively. On the other hand, the form factor for beams with I and box-shaped sections has been found to be less than unity and may in extreme instances be as small as 0.50.

The stresses developed in a wooden beam also depend on its size—or rather its depth. In general, the shallower the beam the greater the stresses that will be developed and conversely. This effect is sufficient to make about 7 percent difference between depths of 8 and 2 inches.

Theoretically, also, the stresses developed are affected by the width of the piece. As far as is known, this effect is not sufficiently large to be of practical significance. If, however, the width is too small in comparison with the height and span a beam may deflect sideways and fail at a lower stress than would a wider beam with other dimensions the same or than the same beam if braced against deflection sideways (*52*).

The effects of shape and depth of beams as just discussed apply to loads and stresses. Modulus of elasticity is not affected. Consequently, the same value of modulus of elasticity may be used for computing deflections by the usual engineering formulas regardless of the shape or depth of a beam. When, however, the relation of depth to span is such that high horizontal shearing stress is involved, the effect of shearing deformation should be considered in computing deflections (*35*).

DEFECTS

Defects are any irregularities occurring in or on wood that may lower some of the strength, durability, or utility values. Defects may be divided into two groups on the basis of their effect on structural timbers: (1) Those that materially affect the strength and must be considered in formulating specifications. This group includes decay, cross grain, knots, shakes, checks, and splits; and structural grading rules definitely limit the sizes of such defects according to the grade (*9, 33, 34, 61*). (2) Those that would normally be excluded for other reasons than their effect on the strength. This second group includes pitch pockets, wane, wormholes, warp, pith, and imperfect manufacture. These may ordinarily be disregarded in grading structural timbers but must be considered in selecting material of smaller size for special uses, such as handles or ladder parts.

DECAY

Vegetable organisms known as fungi, of which there are many varieties, are the cause of decay or rot in timber. Aside from food, which is supplied by the wood, the three essentials to their development are air, suitable temperature, and favorable moisture content. Wood that is completely submerged in water does not decay because the necessary air is lacking. Wood whose moisture content is constantly below about 16 percent does not decay because insufficient moisture is available for decay-producing organisms. The so-called dry rot develops in timber that is apparently below such a moisture content because the producing organism is capable of conducting the needed moisture from sources outside the timber itself.

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Wood decays more rapidly in warm humid climates than in cool dry regions. High altitudes are as a rule less favorable to decay than nearby low areas because the average temperature is lower and the growing season for fungi is shorter.

Not all properties are affected to the same extent by a given degree of decay. Shock-resisting ability as reflected in the work values in static bending, or the height of drop in impact bending, is one of the first properties to be affected, and decay which has not progressed far enough to be visible may seriously impair this quality. Crushing strength parallel to the grain is slowest to give way, with hardness and strength as a beam holding an intermediate position. Decay often develops in localized regions or pockets and may not affect the strength of a piece uniformly.

Because of the fact that it is impossible to estimate satisfactorily either the extent to which decay has progressed, or the probability of its further development, timber containing decay in any stage should be regarded with misgiving for use where strength is important.

Two methods are available for prolonging the life of timber exposed to conditions favorable to decay: (1) Use the heartwood of species that are naturally resistant to decay; (2) impregnate the wood with a preservative (*18*).

The danger of decay can in many instances be lessened materially by careful attention to details of design and construction. For example, proper insulation of water pipes will prevent excess humidity and the deposition of water on woodwork in their vicinity; joints in exterior woodwork can be made so that they are readily drained or ventilated; ventilation can be provided beneath the floors of houses without basements; basement posts or columns can be raised a few inches above the floor by means of pedestals.

The sapwood of all species has low natural decay resistance and generally short life under decay-producing conditions. Common native species vary greatly with respect to the durability of the heartwood. Furthermore, all pieces of the heartwood of a species are not equally durable.

General comparisons of the relative decay resistance of different species must be estimates. They cannot be exact and they may be very misleading if interpreted as mathematically accurate and applicable in all instances. They may be very useful, however, if understood as approximate averages only, from which specific cases may vary considerably, and as having application only where conditions are favorable to decay. The classification of a number of common native species with respect to the durability of the untreated heartwood as presented in table 7 is to be so understood.

CROSS GRAIN

The term "cross grain" denotes any deviation of wood fibers from a direction parallel to the longitudinal axis of a piece.

In order to correlate cross grain with the strength properties of timber, a definite method of measurement is necessary. This is afforded by the angle between the direction of the fibers and the axis of the piece, or edge if it is parallel to the axis. The angle is usually expressed as a slope; for instance, 1 in 15, or 1 to 15, means that the grain deviates 1 inch from the edge of the piece in a distance of 15 inches.

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An extensive series of tests on Sitka spruce, Douglas fir, and commercial white ash has shown that the several strength properties differ in the degree to which they are affected by cross grain and that for properties materially affected the tendency of values to fall off occurs with even slight deviations of grain (*19*, *57*). Values presented

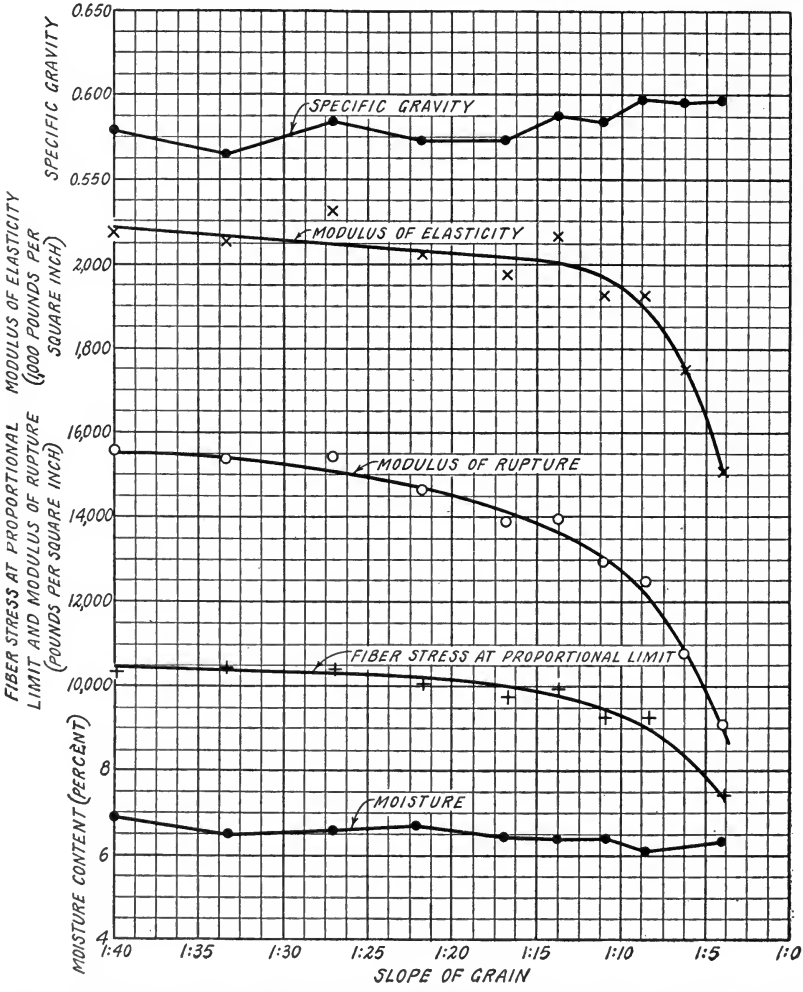

FIGURE 13.—Effect of spiral and diagonal grain on fiber stress at proportional limit, modulus of rupture, and modulus of elasticity in static bending on white ash.

in table 18 are the average percentage deficiencies for various slopes of cross grain in material that is free from checks and other defects, as compared with straight-grained stock. Figure 13 presents the results for white ash graphically. Specific gravity and moisture content are plotted in this figure merely to show that they do not vary greatly among the groups of material representing various slopes of grain.

TABLE 18.—*Average percentage deficiency in strength properties of cross-grained material of various slopes with respect to straight-grained material*

[From tests of kiln-dried material with moisture content as shown in fig. 13]

Species of wood and slope of grain	Static bending			Impact bending maximum drop	Compression parallel to grain, maximum crushing strength
	Modulus of rupture	Modulus of elasticity	Work to maximum load		
White ash:					
1:25	4	2	9	6	0
1:20	6	3	17	12	0
1:15	11	4	27	22	0
1:10	18	7	43	37	1
1:5	36	22	61	59	7
Douglas fir:					
1:25	7	4	17	1	
1:20	10	6	24	4	
1:15	15	8	34	13	
1:10	25	14	46	31	
1:5	54	40	68	65	
Sitka spruce:					
1:25	2	2	14	8	
1:20	4	4	21	13	
1:15	8	7	33	22	
1:10	17	13	55	45	
1:5	44	36	76	69	
Average:					
1:25	4	3	13	5	
1:20	7	4	21	10	
1:15	11	6	31	19	
1:10	19	11	48	38	
1:5	45	33	68	64	

The weakening effect of cross grain results from the wide difference in properties of wood along and across the grain. Cross grain is accompanied by an increased variability of properties, increased checking, and a tendency of the wood to twist and warp.

The data presented on the influence of cross grain are based on tests of clear pieces 2 by 2 inches in cross section, free from checks. In larger sizes, and when other defects are present, checks are apt to be present along with the cross grain, and in such instances greater weakening occurs than in the test results cited. The values given are thus indicative of the minimum effect.

The weakening effect on stress in extreme fiber in bending becomes significant with a slope of about 1 in 20 and increases rapidly with increase in slope. The permissible slope of grain depends on the use to which the wood is put. In general a slope greater than 1 in 20 should not be permitted in a main structural aircraft member. In structural timbers, the permissible slope varies with the grade and with the kind of stress, and ranges from 1 in 20 for high-grade beams to 1 in 8 for low-grade posts.

Cross grain may be of three fundamentally different types as follows:

DIAGONAL GRAIN

This form of deviation of grain is caused by failure to saw parallel to the annual growth layers because of either crooked logs, carelessness in manufacture, or the practice of sawing parallel to the pith instead of parallel to the bark in logs of large taper. Diagonal grain shows on the edge-grain or quarter-sawed face of a board or timber.

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SPIRAL GRAIN

This form of deviation of grain results from a corkscrew or spiral rather than vertical arrangement of fibers in a tree. Spiral grain thus refers to the direction of fibers within the annual growth layers and its true direction is evident only on a plain or flat-sawed surface where it is measured by the direction of checks, splits, or other indication of the direction in which the grain runs. Interlocked grain is a special form of spiral grain varying in slope or reversing slope between successive growth periods. An approximation to spiral grain results when a piece is cut so that the grain of the wood on the flat-sawn face is at an angle to the axis.

IRREGULAR GRAIN

This term applies to a more or less irregular wood structure usually accompanying knots, or occasionally appearing as waves in otherwise clear wood.

METHODS OF CALCULATING CROSS-GRAIN

When the grain slopes on both flat-sawn and quarter-sawn faces of a piece these slopes being 1 in a and 1 in b, the resultant or effective slope is given by the expression

$$\frac{\sqrt{a^2+b^2}}{ab};$$

for example, if the slopes are 1 in 12 and 1 in 5 the effective slope is

$$\frac{\sqrt{5^2+12^2}}{5\times 12}=\frac{13}{60}=1 \text{ in } 4.6,$$

or if the slopes are both 1 in 20 the effective slope is

$$\frac{\sqrt{20^2+20^2}}{20\times 20}=\frac{28.3}{400}=1 \text{ in } 14.1$$

KNOTS

A knot is that portion of a branch which has become incorporated in the body of a tree. The influence on strength is due to the fact that the knot interrupts the continuity and direction of fibers and that the direction of fibers in the knot is essentially at right angles to those in the adjacent wood.

The influence of knots depends on their size, location, shape, and soundness; the kind, size, and proportions of the piece; the kind of stress to which the piece is subjected; and the amount of the attendant cross-grain.

Knots actually increase hardness and strength in compression perpendicular to grain, and are objectionable in regard to these properties only to the extent that they cause nonuniform wear or a nonuniform distribution of pressure at contact surfaces. Knots, however, are harder to work and machine than the surrounding wood, may project from the surface when shrinkage occurs, and also are a cause of twisting.

Knots have relatively little effect on the stiffness of a member. Hence, it is possible to effect some economy by using low-grade material where stiffness is the controlling factor as in joists in small buildings. In such instances the size of the member is usually governed by stiffness, and hence relatively knotty material can be satisfactorily used, although at some sacrifice of bending strength. For example, tests of two 2- by 8-inch by 10-foot joists cut from the same species showed, in pounds per square inch, a modulus of elasticity of 1,100,000 and a modulus of rupture of 5,470 for a practically clear joist and a modulus of elasticity of 1,246,000 and a modulus of rupture of 2,940 for a knotty joist. The slightly higher modulus of elasticity of the knotty joist is attributed to the slightly higher specific gravity of the wood over that of the clear joist.

In a long column, that is, a column in which the length exceeds about 20 times its least dimension, the maximum load depends on the stiffness alone, and knots are consequently less detrimental than in a short column in which the crushing strength of the wood determines the maximum load (*32*).

Knots have approximately one-half as much effect on compressive as on tensile strength. Hence, for a given percentage reduction in strength larger knots are permissible in a short column than on the tension side of a beam.

Knots are most serious in their effect on the bending strength of beams. The influence of a knot on the tension face is approximately measured by the ratio of the diameter of the knot to the width of the face, the diameter being taken as the distance between lines enclosing the knot and parallel to the edges of the face. Thus, a knot which measures one-fourth the width of the tension face reduces the bending strength 25 percent. The same knot on the compression side of the beam would have about half the influence. Large knots have a somewhat greater influence on the bending strength than is indicated by the foregoing rule, owing to the increased distortion of grain around them. This effect is taken care of in the structural grading rules conforming to American lumber standards (*54*, *61*). The effect of knots is greater in the center half of the length of a beam than near the ends, and is greater near the upper and lower faces than at the center of the height (*9*).

SHAKES

A shake is a separation of wood along the grain, the greater part of which occurs between or within the rings of annual growth. Shakes can best be detected at the end of the piece where they extend in a general circumferential direction. In structural grading, shakes that appear on an end of a piece are assumed to extend to the center of its length. In beams the principal effect of shakes and one effect of checks is to reduce resistance to horizontal shear or the sliding of the upper on the lower part of the piece. Not only do shakes and checks reduce the area acting in resistance to shear but because of concentration of stress at their extremities the average shearing strength of the remaining area is much less than the shearing strength of unchecked wood as found from shear or torsion tests. These effects are important in large timbers in which the concentration of stress accompanying shakes and/or the checking that usually occurs either prior or subsequent to the placement of timbers in service is sufficient to cause failure at a shearing stress, as averaged over the unchecked area, of

less than half the ultimate value found in standard shear block tests (table 1). The effect of shakes on strength in horizontal shear is appraised in the grading of beams by determining the width of the shake, as measured on the end between lines parallel to the faces, in terms of the width of the piece. For green timbers the allowable shake is the same percentage of the width of the piece as the grade is below an assumed strength for the clear wood (*61*). Thus, in beams of a grade that permits defects that reduce the strength by one-fourth, the allowable shake would be one-fourth the width of the piece. Shakes tend to increase in size with seasoning. A slightly larger shake is allowable in seasoned material.

CHECKS

A check is a separation along the grain, the greater part of which occurs across the rings of annual growth. Checks other than heart and star checks which occur in green wood and whose cause is unknown occur in seasoning and are due to difference in shrinkage in radial and tangential, or circumferential, directions, and to difference in shrinkage between adjacent parts induced by differences in moisture content. Checks are classed as end checks, heart checks, star checks, surface checks, and through checks. An end check is one at an end of a piece; a heart check is one starting near the pith and extending toward but not to the surface of the piece; a star check consists of a number of heart checks; a surface check is one into a piece from the surface, and a through check is one extending through the piece from one surface to another. Difference between forms of checks need not be considered in determining their effect on strength.

Checks, like shakes, are injurious to beams to the extent that they reduce the area resisting horizontal shear. It is evident that checks in the narrow or horizontal face have practically no effect upon the strength of straight-grained beams. Checks in the wide or vertical faces are most serious in their effect on resistances to horizontal shear when straight and at or near the center of the height.

The effect of checks in beams and columns depends on the area of the longitudinal section they cover, but, unlike shakes, they are not assumed to extend from the end of the piece to the center of the length. The same method of measurement and limitation may be applied as for shakes. If more refinement is desired, however, it may be obtained by estimating the actual reduction of area in a longitudinal plane within that portion of the length extending from the end to a distance three times the depth from the end. The aggregate area of checks permissible within this distance is equal to the width of the allowable shake multiplied by three times the height of the beam (*61*).

Checks also cause serious weakening in tension perpendicular to grain, but are less injurious in straight-grained members subjected to direct compression or tension along the grain.

Checks are more difficult to prevent in large timbers than in small pieces, and they increase in size and depth with the degree of seasoning during the earlier stages but later close partially or entirely. Checks usually appear first on the ends of a piece, but the development of end checks can be retarded, and in smaller sizes prevented, by the application of an end coating, such as hardened gloss oil prior to seasoning. Season checks form in round timbers because the radial shrinkage differs from the tangential or circumferential.

PITCH POCKETS

Pitch pockets are openings within or between the annual growth rings that contain more or less pitch or bark. Pitch pockets vary greatly in size. Ordinarily, their dimension at right angles to the annual rings is less than one-half inch, whereas they may extend for several inches along the grain (vertically in the tree) and/or in the direction of the annual rings (circumferentially in the tree).

Native species in which pitch pockets are found are the pines, the spruces, Douglas fir, western larch, and tamarack. Pitch pockets in structural timbers ordinarily are not important as (1) their extent is not sufficient to cause significant weakening in shear, (2) they do not cause serious deviations of grain, and (3) they occupy only a small proportion of the cross section of a piece. However, numerous pitch pockets in or close to the same annual growth layer may denote the presence of shakes or may be equivalent in effect to a shake.

In small members the size of the pitch pockets may represent an appreciable portion of the cross section and be located so as to have a marked effect on the strength.

The weakening effect of pitch pockets is more serious when they cause distortion or "dip" of the grain. It is, of course, necessary to limit pitch pockets in aircraft parts, and rules have been established for this purpose (*53*, *55*) but in general they are of importance chiefly because of their effect on appearance.

COMPRESSION FAILURES

A compression failure is a local buckling of the fibers, essentially at right angles to the length, due to excessive compression along the grain. Compression failures appear as wrinkles on the surface of a piece, and range from a well-defined buckling of the fibers visible with the unaided eye to a slight crinkling visible only with a microscope (*7*, *21*, *25*).

Compression failures may occur when standing trees are bent severely by wind or snow, when trees are felled over logs or irregularities of the ground, from rough handling of logs or sawed stock, and excessive stresses in service. They weaken the wood in tension, and when on the tension side of a beam produce brash appearing and sudden failures. Material containing compression failures should be rejected for uses in which strength and shock resistance are important, such as in handles and ladder parts. Compression failures are usually so inconspicuous that careful search is necessary to detect them. Often tilting of a piece of wood with respect to the line of vision or source of light will help make them visible. It is seldom possible to detect them in rough-sawn material.

The results of static bending tests on four specimens from a board containing compression failures sufficiently prominent to be readily detected, as compared with the average of uninjured material are given in table 19. These data, while but fragmentary, illustrate the serious reduction in modulus of rupture caused by pronounced compression failures, the even greater reduction in shock resistance as shown by work to maximum load. and the variability in strength properties which they cause.

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TABLE 19.—*Results of static bending test on 4 specimens* [1] *from a board containing prominent compression failures*

Kind of specimen	Specific gravity [2]	Moisture content	Modulus of rupture	Work to maximum load
		Percent	*Lb. per sq. in.*	*In.-lb. per cu. in.*
Containing compression failures	0.53	10.3	5,770	1.44
	.48	11.3	3,050	.59
	.46	11.2	2,510	.38
	.52	11.3	5,830	1.30
Average figures for uninjured material	.45	12	10,690	7.8

[1] The bending tests were made on specimens ¾ by 2 by 20 inches, using center loading and an 18-inch span. Specimens 1, 2, 3, and 4 were cut so that the compression failures were located at the center of the span.

[2] Specific gravity based on weight when oven dry and volume when green.

COMPRESSION WOOD

Compression wood, also known as red wood (rotholz), is wood of abnormal growth and structure, slightly above the average in weight, which is usually distinguished by very wide and eccentric annual rings, a lack of contrast between spring and summer wood, and a more or less dark-reddish to brown color. This growth occurs on the under side of limbs and leaning trunks of coniferous trees (*16*, *21*).

Table 20 compares compression wood with normal wood in ponderosa pine, southern yellow pine, and redwood. The values given should not be regarded as the true averages either for normal wood or compression wood, but as indicative of the relationships between the two types. The reason for this is that compression wood varies greatly in degree from material bordering on normal wood to pronounced types. The normal wood represented was cut from the same pieces as the compression wood, and hence was selected to match the latter rather than to be representative of the species.

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TABLE 20.—*Strength properties of compression wood compared with normal wood of redwood, ponderosa pine, and southern yellow pine* [1]

Average values	Redwood				Ponderosa pine				Southern yellow pine, air-dry	
	Green		Air-dry		Green		Air-dry			
	Normal wood	Compression wood	Normal wood	Compression wood	Normal wood	Compression wood	Normal wood	Compression wood	Normal wood	Compression wood
Specific gravity, based on oven-dry volume									0.57	0.66
Shrinkage, longitudinal, green to oven-dry ..... percent	0.14	1.19			0.21	0.80			.4	2.5
Shrinkage, radial, green to oven-dry ..... do	2.4								4.6	2.2
Shrinkage, tangential, green to oven-dry ..... do	4.0								6.2	2.6
Static bending:										
Moisture content ..... do	114	102	9.9	10.5	133	88	12.0	12.6	11.6	12.4
Specific gravity, based on volume as tested	.38	.51	.38	.51	.35	.47	.37	.50		
Fiber stress at proportional limit ..... pounds per square inch					3,010	3,730	7,250	6,620	8,550	6,520
Modulus of rupture ..... do	7,310	7,470	10,210	8,890	4,640	6,120	9,840	11,710	11,730	9,000
Modulus of elasticity ..... 1,000 pounds per square inch	1,110	685	1,253	788	1,074	842	1,345	1,019	1,495	994
Work to proportional limit ..... inch pounds per cubic inch					.47	.94	2.19	.63		
Work to maximum load ..... do	7.5	6.9	6.0	6.5	4.0	8.8	7.6	15.7	8.2	5.5
Work, total ..... do					14.4	45.6	10.8	16.2		
Toughness:										
Moisture content ..... percent	129	89	8.8	9.7	121	85	10.0	10.6		
Specific gravity, based on volume as tested	.37	.52	.37	.49	.37	.49	.38	.53		
Toughness per specimen ..... inch-pounds	83.0	69.5	64.5	64.4	100.7	173.4	79.2	100.4		
Compression parallel to grain:										
Moisture content ..... percent	126	106	8.6	10.0	138	78	12.1	12.7	11.7	10.8
Specific gravity, based on volume as tested	.37	.51	.38	.51	.35	.47	.37	.50	.55	.68
Crushing strength at proportional limit ..... pounds per square inch	3,950	4,640	7,160	7,250	2,140	2,090				
Maximum crushing strength ..... do					2,340	3,300	5,210	5,970	7,370	8,100
Modulus of elasticity ..... 1,000 pounds per square inch					1,476	996				

[1] Exact species unknown.

It may be noted that compression wood is characterized by high longitudinal shrinkage, by low stiffness, and for its weight, a general deficiency in most other properties.

When compression wood and wood of normal structure are present in the same piece very high stresses are set up in drying on account of the large difference in longitudinal shrinkage of the two types of wood. This causes bowing or other distortion and may even result in splitting of the piece or in tension failure in the compression wood.

INSECT HOLES

The effect of wormholes on strength is somewhat similar to that of knots or knot holes, except that they do not involve distortion of grain. Inasmuch as wormholes found in lumber usually have only small diameters, occasional ones do not seriously weaken the wood.

In lumber which has been in storage for some time wormholes may be more serious on the interior than is indicated on the surface. This is especially true of the sapwood of ash, oak, hickory, elm, and some other hardwoods that are subject to attack by the powder post beetle (*45*).

SAP STAIN

Sap stains (blue, red, and yellow) are caused by organisms which germinate in the sapwood, absorbing starches and sugars. Most sap stains, unlike wood-destroying fungi, do not as a rule penetrate the cell walls and consume the wood substance, and therefore sap stain is not in itself so serious from the strength standpoint. However, severe sap stain of certain varieties causes sufficient injury to appreciably reduce the shock resistance or toughness.

Sap stain exerts a marked effect on appearance. Its presence, furthermore, indicates that the wood has been subjected to unfavorable conditions and the possible development of wood-destroying fungi should be considered in the use of such material (*17*).

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APPENDIX

DETAILS OF TEST PROCEDURE

The information on strength and related properties of woods grown in the United States, which is given in table 1, was obtained from tests in static bending, impact bending, compression parallel to grain, compression perpendicular to grain, hardness, shear parallel to grain, tension perpendicular to grain, and cleavage. Data on weight and shrinkage were also obtained by means of standardized tests. The foregoing 8 tests furnish information on more than 25 different properties of wood.

SELECTION OF MATERIAL

The material for test was identified botanically in the woods, and was brought to the Forest Products Laboratory in the green condition in log form. The logs were generally 4 or 8 feet in length and were usually taken from each of five or more representative trees of each species, the upper end of the log selected being in most instances 16 feet above the stump. Each 4-foot log or bolt was divided into sticks as shown in figure 14. Insofar as was possible without testing pieces having imperfections that would reduce their strength, the following procedure was followed: A test in compression parallel to the grain was made on a specimen from each stick and a test in static bending on a specimen from one stick of each pair. A pair consists of two tangentially adjacent sticks as N1 and N2, W7 and W8, and so forth. Tests in compression perpendicular to grain were made on specimens cut from one-half the sticks that supplied the static bending specimens, and hardness tests on the other half. Sticks from various parts of the cross section were tested in impact bending, shear, cleavage, and tension perpendicular to grain. This was the system followed when the tree furnished material for tests in the green condition only. For each species from each locality tests were also made on both green and air-dry material from one or more trees. Two adjacent bolts from each of such trees were cut into sticks as indicated by figure 14. Two composite bolts each consisting of one stick from each pair from each of the two adjacent bolts were then formed. The sticks from one composite bolt were tested in the green condition, those from the other after air drying; the assignment of sticks to the various tests being as previously described. This system of division of logs and assignment of sticks provided tests of each kind from various parts of the cross section of the log and afforded for test air-dry material closely matched to that tested in the green condition.

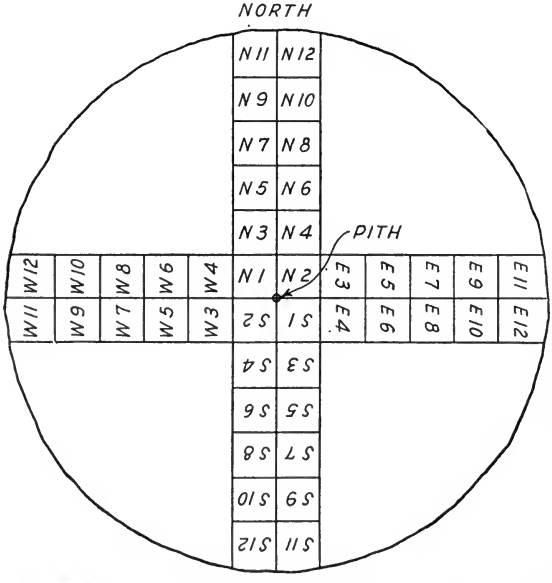

FIGURE 14.—Method of cutting up the bolt and marking the sticks.

A further feature was the testing in a similar manner of green material taken at various heights above the stump from one or more trees of a number of species. The resulting data are not tabulated herein but are the basis of the discussion of variation of properties with height in tree (p. 40).

TESTING METHODS

The detailed procedure of testing conformed closely to standards of the American Society for Testing Material (*4*). Specimens for mechanical tests are 2 by 2 inches in cross section and of different lengths, depending on the kind of test. Those for radial and tangential shrinkage are 1 inch thick, 4 inches wide, and 1 inch in length along the grain, the width being radial or tangential according to

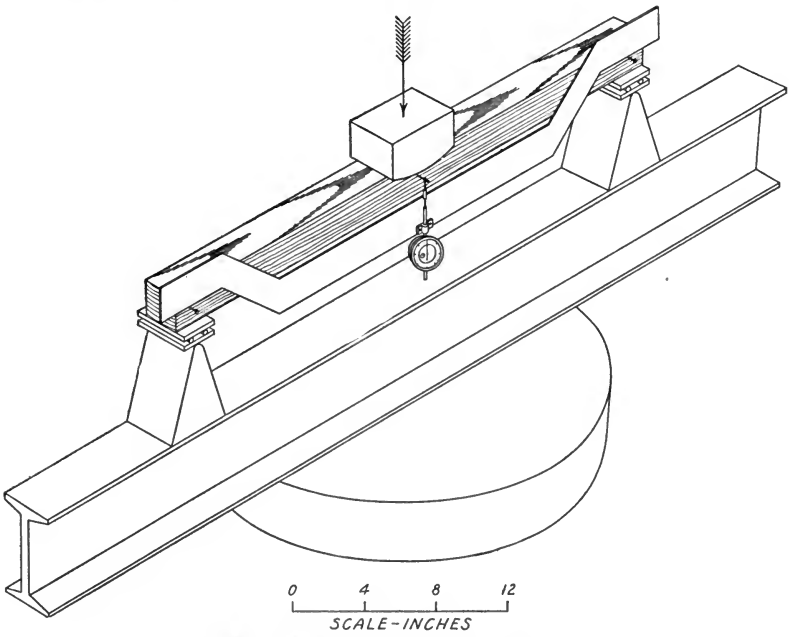

FIGURE 15.—Method of conducting static-bending test.

whether radial or tangential shrinkage is to be measured. Moisture determinations are made on all test specimens.

Only specimens free from knots, cross grain, shakes, checks, and the like were tested. The effects of such characteristics on strength values has been investigated in other tests (*9*).

A brief outline of the procedure in making each kind of test and of computing the results follows.

DESCRIPTION OF TESTS

STATIC BENDING

In the static-bending test resistance of a beam to slowly applied loads is measured. The specimen is 2 by 2 inches in cross section and 30 inches long and is supported on roller bearings which rest on knife edges placed 28 inches apart (fig. 15). Load is applied at the center of the length through a hard maple block, $3\frac{13}{16}$ inches wide, having a compound curvature. The curvature has a radius of 3 inches over the central $2\frac{1}{8}$ inches of arc, and is joined by an arc of 2 inches radius on each side (fig. 15). The standard placement is with the annual rings of the specimen horizontal. A constant rate of deflection (0.1 inch per minute) is maintained until the beam fails. Load and deflection are read simultaneously at suitable intervals. Figure 16 is a sample data sheet on which such readings are plotted and other information is shown, and figure 17 is a sample computation data card. In figure 16 it may be noted that a line is drawn through the origin parallel to that through the initial points of the curve in order to determine the deflection at proportional limit.

Data on a number of properties are obtained from static-bending tests, the most important of which are stress at proportional limit, modulus of rupture, modulus of elasticity, work to proportional limit, work to maximum load, and total work, discussions of which follow.

STRESS AT PROPORTIONAL LIMIT

As may be noted the first several plotted points in figure 16 are approximately on a straight line showing that the load is proportional to the deflection. As the test progresses, however, the load ceases to increase in direct proportion

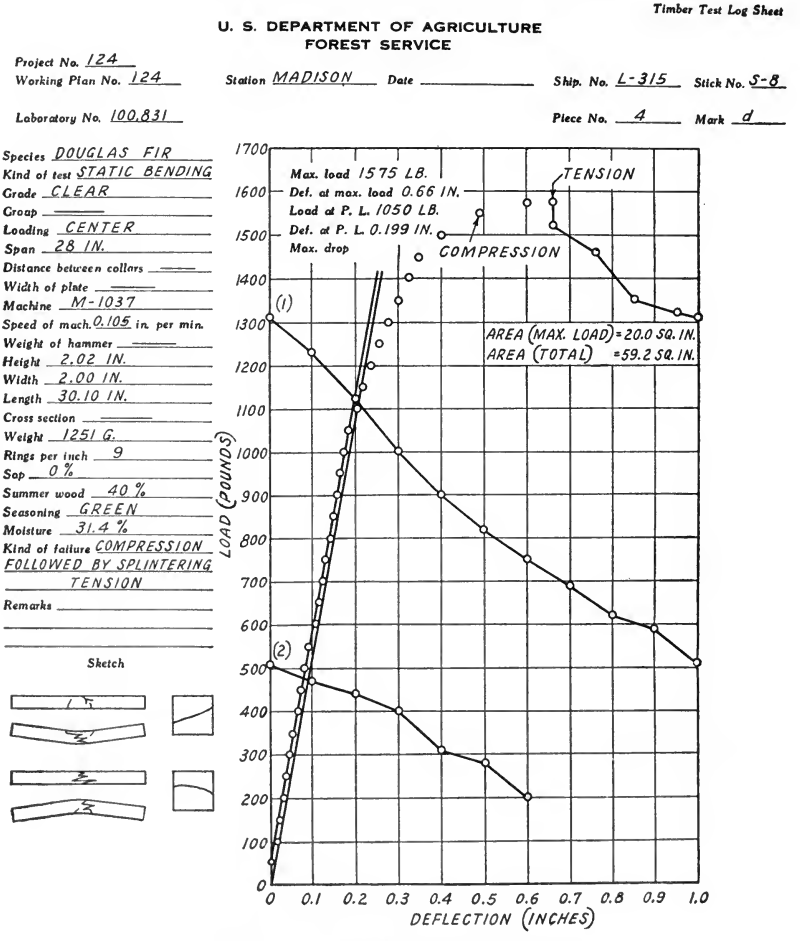

FIGURE 16.—Data sheet for static-bending test.

to the deflection. The point where this occurs, at a load of 1,050 pounds in figure 16, is known as the proportional limit. The corresponding stress in the top and bottom fibers of the beam is the stress at proportional limit.

Using formula 1 on page 98, the stress at proportional limit for the specimen represented by figure 16 is

$$S_{PL}=\frac{3\times 1050\times 28}{2\times 2.00\times (2.02)^2}=5{,}400 \text{ pounds per square inch}$$

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MODULUS OF RUPTURE

The modulus of rupture is computed by the same formula as stress at proportional limit, using the maximum load instead of the load at proportional limit. From formula 2 (p. 98), the modulus of rupture of the test specimen of figure 16 is

$$R=\frac{3\times 1{,}575\times 28}{2\times 2.00\times (2.02)^2}=8{,}110 \text{ pounds per square inch}$$

MODULUS OF ELASTICITY

The modulus of elasticity is determined by the slope of the straight line portion of the load-deflection graph (fig. 16), the steeper the line the higher being the modulus. From formula 3 (p. 98), the modulus of elasticity of the test specimen of figure 16 is

$$E=\frac{1{,}050\times (28)^3}{4\times 2.00\times (2.02)^3\times 0.199}=1{,}757{,}000 \text{ pounds per square inch}$$

The value of 0.199 used in this computation is the deflection in inches at the proportional limit.

Form 507. (Revised January,)

STATIC BENDING

L-315 (Ship No.) S-8 (Stick No.) CENTER Loading 100 831 (Lab. No.)

4 (Piece No.) d (Mark.) Station MADISON Date AUG. 24, 124 (Project No.)

Species DOUGLAS FIR Grade CLEAR Seasoning GREEN

Rings 9 Sap 0 % Summer wood 40 % Moisture 31.4 %

Span 28 IN. Length 30.10 IN. Height 2.02 IN. Width 2.00 IN. Weight 1251 G.

SPECIFIC GRAVITY. AS TEST.	SPECIFIC GRAVITY. OV. DRY.	F. S. AT P. L.	M. OF R.	M. OF E.	SHEAR.	WORK TO P. L.	WORK TO MAX. LOAD.	TOTAL WORK.	
0.628	0.478	5410	8120	1756	292	0.92	7.1	20.9	

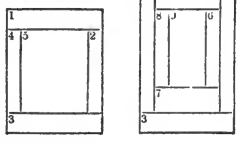
Rings: Up. ¼ Mid. ½ Low. ¼

Sum. wood: Up. ¼ Mid. ½ Low. ¼

Defects

Failure COMPRESSION FOLLOWED BY SPLINTERING TENSION

MOISTURE DISTRIBUTION.



b—1434

FIGURE 17.—Sample computation card for static-bending test.

WORK TO PROPORTIONAL LIMIT

Work to proportional limit is the product of the average load up to the proportional limit times the deflection at the proportional limit. It is represented by the area under the load-deflection curve from the origin to a vertical line through the abscissae representing the deflection at proportional limit, and is expressed in inch-pounds per cubic inch (fig. 16). From formula 5 (p. 98), the work to proportional limit for the test specimen of figure 16 is

$$W_{PL}=\frac{1{,}050\times 0.199}{2\times 2.00\times 2.02\times 28}=0.92 \text{ inch-pounds per cubic inch}$$

WORK TO MAXIMUM LOAD

The work to maximum load is represented by the area under the load-deflection curve from the origin to the vertical line through the abscissae representing the maximum deflection at which the maximum load is sustained. It is expressed in the same units as work to proportional limit.

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From formula 6 (p. 98), the work to maximum load for the test specimen of figure 16 is

$$W_{ML}=\frac{20\times200\times0.2}{2.00\times2.02\times28}=7.1 \text{ inch-pounds per cubic inch}$$

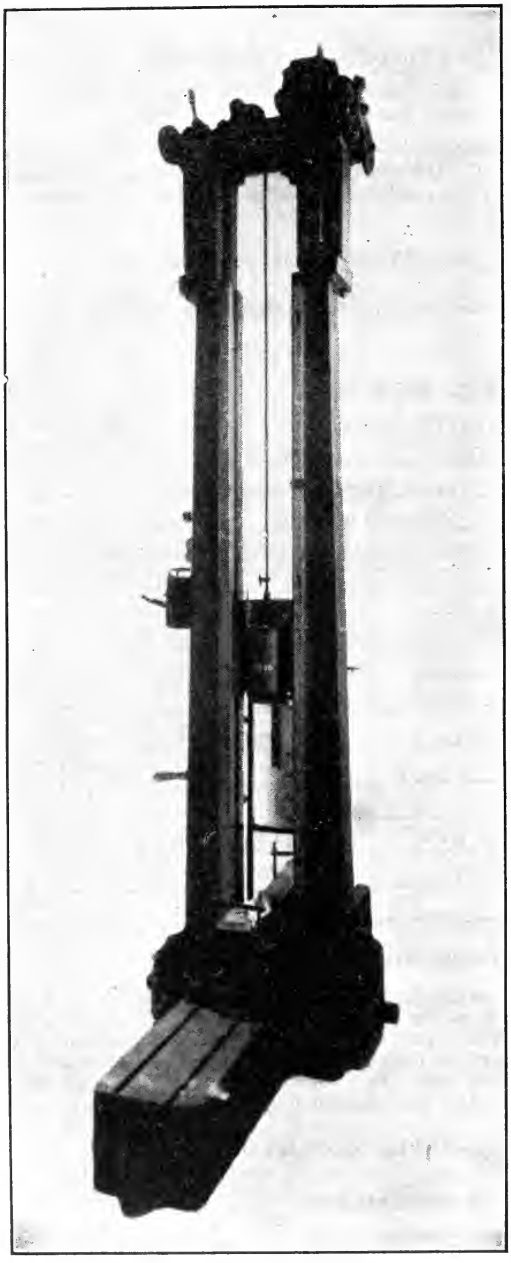

FIGURE 18.—Machine used for impact-bending test.

(The area under the curve in the graph reproduced in figure 16 was 20 square inches, and with the scales used in plotting, each square inch represents 200 (pounds) times 0.2 (inch) or 40 inch-pounds.)

TOTAL WORK

The total work is represented by the complete area under the curve from the beginning of the test until it is discontinued. The test is arbitrarily discontinued in this series when the load after attaining its maximum value first decreases to 200 pounds, or when a deflection of 6 inches is reached, whichever occurs first.

From formula 7 (p. 98), the total work for the test specimen of figure 16 is

$$W_T=\frac{59.2\times40}{2\times2.02\times28}=20.9$$

inch-pounds per cubic inch

The total area under the curve in the original graph represented by figure 16 was 59.2 square inches.

IMPACT BENDING

The impact-bending test is made to determine the resistance of beams to suddenly applied loads. The specimen is 2 by 2 inches in cross section and 30 inches long, and the span is 28 inches. A 50-pound ram or hammer falling between two vertical guides is dropped upon the stick at the center of the span; first from a height of 1 inch, next 2 inches, and so on to 10 inches, then increasing 2 inches at a time until complete failure occurs (fig. 18). A stylus attached to the hammer moves against paper mounted on a revolving drum and records the deflection at each blow, and the position of the specimen when the hammer comes to rest after rebounding. Thus, data are obtained for determining various properties of the wood. Figure 19 is a sample record taken on the drum. Figure 20 is a sample computation card, and figure 21 is a sample data sheet on which the test results are plotted to determine the stress at propor-

tional limit and the modulus of elasticity. Other properties on which data are obtained are height of drop in impact bending and work to proportional limit.

STRESS AT PROPORTIONAL LIMIT

In figure 21, height of drop is plotted against the square of the deflection. The first several points are approximately on a straight line, and are used to determine the limit of proportionality. Practically all the factors influencing the test tend to reduce the deflection for a given height of drop, so that after finding the deflection at proportional limit as usual, the head or drop at this deflection is read from a line passing through the origin and the point within the proportional limit which gives this line the least slope. From formula 13 (p. 98), the stress at proportional limit for the specimen represented by figure 21 is

$$S_{PL}=\frac{3\times 50\times 7.88\times 28}{2.00\times(2.00)^2\times 0.39}=$$

10,610 pounds per square inch

WORK TO PROPORTIONAL LIMIT

The work to proportional limit is equivalent to the energy of the drop that stresses the piece to the proportional limit. From formula 14 (p. 98), the work to the proportional limit for the test specimen of figure 21 is

$$W_{PL}=\frac{50\times 7.88}{28\times 2\times 2}=3.51$$

inch-pounds per cubic inch

HEIGHT OF DROP

The height of drop is recorded as the maximum drop of the hammer causing complete failure of the specimen, or causing a 6-inch deflection. When it is necessary to use a hammer heavier than the 50-pound standard, the height of drop is converted to the equivalent value for a 50-pound hammer.

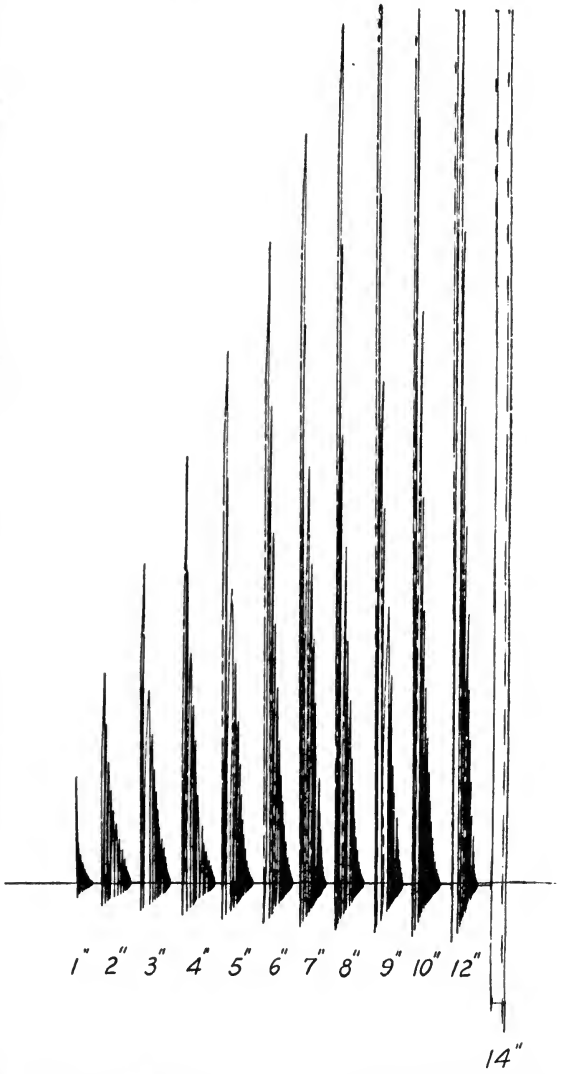

FIGURE 19.—Record taken on the drum of the impact-bending machine in testing northern white pine in a green condition. A maximum drop of 14 inches is recorded.

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Form 500 (Revised Jan.,

L-315 (Ship. No.) E-12 (Stick No.)

IMPACT BENDING

101151 (Lab. No.)

1 (Piece No.) C (Mark) Station MADISON Date AUG. 20, 124 (Project No.)

Species DOUGLAS FIR Grade CLEAR Seasoning GREEN

Rings 8 Sap 100 % Summer wood 30 % Moisture 61.4 %

Hammer 50 lbs. Span 28 IN. Length 29.94 IN. Height 2.00 IN. Width 2.00 IN. Weight 1370 G.

Drop No.	Drop	Def.	(Def.)²	Set.	Drop No.	Drop	Def.	(Def.)²	Set.
1	1.0	0.13	0.017		11	12.0	0.50	0.250	
2	2.0	0.18	0.032		12	14.0	0.55	0.302	
3	3.0	0.22	0.048		13	16.0	0.62	0.384	
4	4.0	0.26	0.068		14	18.0	0.67	0.593	
5	5.0	0.30	0.090		15				
6	6.0	0.34	0.116		16				
7	7.0	0.36	0.130		17				
8	8.0	0.38	0.144		18				
9	9.0	0.43	0.185		19				
10	10.0	0.46	0.212		20				

Sp. Gr. (at test),	0.698
Sp. Gr. (oven dry),	0.432
F. S. at P. L.,	10610
M. of E.,	1776
E. Resil.,	3.51
Max. Drop,	22 IN.
d,	0.010
H	7.88
Δ	0.39

Failure: COMPRESSION FOLLOWED BY SPLINTERING TENSION

FIGURE 20.—Sample computation card for impact-bending test.

8—1431

Timber Test Log Sheet

U. S. DEPARTMENT OF AGRICULTURE
FOREST SERVICE

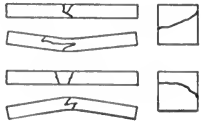
Project No. 124

Working Plan No. 124 Station MADISON Date _____ Ship. No. L-315 Stick No. E-12

Laboratory No. 101,151 Piece No. 1 Mark C

Species DOUGLAS FIR
Kind of test IMPACT BENDING
Grade CLEAR
Group ——
Loading CENTER
Span 28 IN.
Distance between collars ——
Width of plate ——
Machine M-1036
Speed of mach. —— in. per min.
Weight of hammer 50 LB.
Height 2.00 IN.
Width 2.00 IN.
Length 29.94 IN.
Cross section ——
Weight 1370 G.
Rings per inch 8
Sap 100%
Summer wood 30%
Seasoning GREEN
Moisture 61.4 %
Kind of failure COMPRESSION FOLLOWED BY SPLINTERING TENSION
Remarks

Sketch



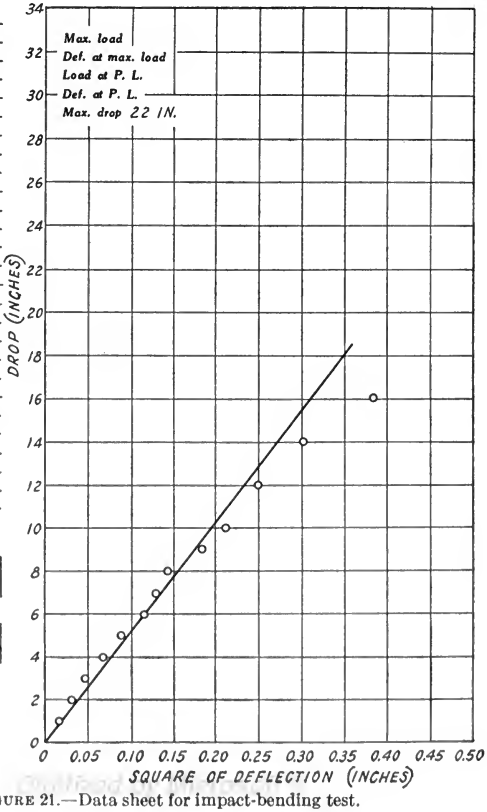


FIGURE 21.—Data sheet for impact-bending test.

COMPRESSION PARALLEL TO GRAIN

In the compression-parallel-to-grain test a 2- by 2- by 8-inch block is compressed in the direction of its length (fig. 22) at a constant rate (0.024 inch per minute). The load is applied through a spherical bearing block, preferably of the suspended self-aligning type, to insure uniform distribution of stress. On some of the specimens, the load and the deformation in a 6-inch central gage length are read simultaneously until the proportional limit is passed. The test is discontinued when the maximum load is passed, and the failure appears. Figure 23 is a sample data sheet on which the test readings are plotted and figure 24 is a sample computation data card.

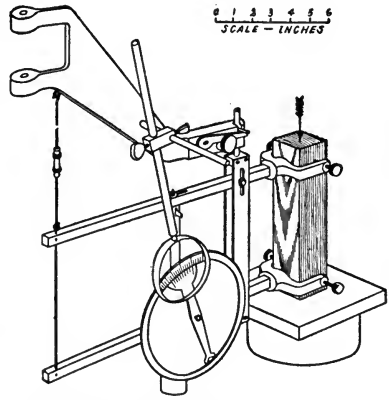


FIGURE 22.—Diagrammatic sketch of compressometer and method of conducting compression-parallel-to-grain tests.

An alternate form of test specimen has a circular cross section 1⅝ inches in diameter except at the ends which are left 2 inches square (4). This specimen requires less exacting technic than the square prism, to get good results in testing, but is less simple to prepare.

Timber Test Log Sheet

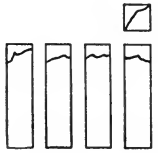
U. S. DEPARTMENT OF AGRICULTURE
FOREST SERVICE

Project No. 124
Working Plan No. 124
Station MADISON Date _____ Ship. No. L-315 Stick No. E-3
Laboratory No. 101329 Piece No. 7 Mark d-1

Species DOUGLAS FIR
Kind of test COMP. PAR. TO GR.
Grade CLEAR
Group ———
Loading ———
Span ———
Distance between collars 6 IN.
Width of plate ———
Machine M 1040
Speed of mach. 0.024 in. per min.
Weight of hammer ———
Height ———
Width ———
Length 7.99 IN.
Cross section 1.97 IN. X 2.00 IN.
Weight 287 G.
Rings per inch 8
Sap. 0 %
Summer wood 26 %
Seasoning GREEN
Moisture 28.7 %
Kind of failure CRUSHING NEAR TOP

Remarks

Sketch



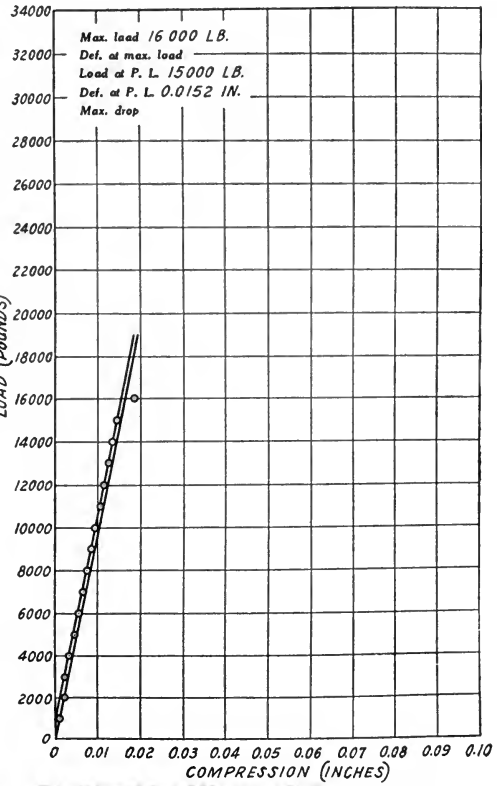


FIGURE 23.—Data sheet for compression-parallel-to grain test.

Form 508
(Revised Nov. 27,

COMPRESSION PARALLEL TO GRAIN

L-315 (Ship. No.) E-3 (Stick No.) 101329 (Lab. No.)

7 (Piece No.) d-1 (Mark) Station MADISON Date AUG. 26, 124 (Project No.)

Species DOUGLAS FIR Grade CLEAR Seasoning GREEN

Rings 8 Sap 0 % Summer wood 26 % Moisture 28.7 %

Length 7.99 IN. Cross section 1.97 IN. x 2.00 IN. Weight 287 G.

Specific Gravity		Max. Load	Crush. St. at P. L.	Max. Crush. St.	M. of E.	Load at P.L.	Def. at P.L.
At Test	Ov. Dry						
0.556	0.432	16000	3810	4060	1502	15000	0.0152

Defects

Failure CRUSHING AT TOP

FIGURE 24.—Sample computation card for compression-parallel-to-grain test.

Data on stress at proportional limit, stress at maximum load (maximum crushing strength), and modulus of elasticity are obtained. The data on modulus of elasticity from this test, however, are not included in table 1.

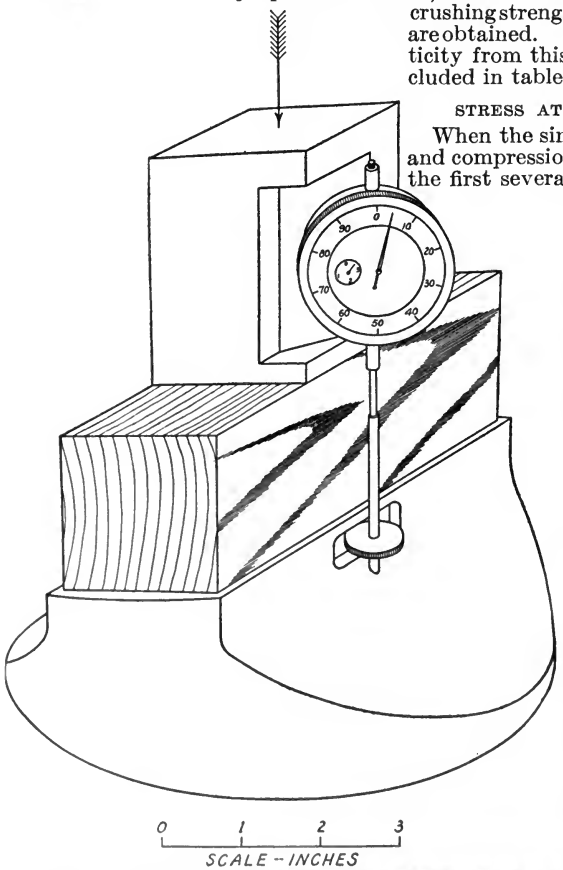


FIGURE 25.—Method of conducting compression-perpendicular-to-grain test.

STRESS AT PROPORTIONAL LIMIT

When the simultaneous readings of load and compression are plotted as in figure 23, the first several points are approximately on a straight line. The point beyond which the compression increases at more rapid rate than the load is the proportional limit, and the accompanying stress is the stress at proportional limit. From formula 15, (p. 98), the stress at proportional limit for the test specimen represented by figure 23 is

$$S_{PL}=\frac{15{,}000}{1.97\times 2.00}=3{,}810$$

pounds per square inch

MAXIMUM CRUSHING STRENGTH

The maximum crushing strength is computed from the same formula as stress at proportional limit, using the maximum load instead of load at proportional limit. From formula 16, (p. 98), the maximum crushing strength of the test specimen of figure 23 is

$$S_c=\frac{16{,}000}{1.97\times 2}=4{,}060$$

pounds per square inch

COMPRESSION PERPENDICULAR TO GRAIN

The specimen for the compression-perpendicular-to-grain test is 2 by 2 inches in cross section and 6 inches long. Pressure is applied through an iron plate 2 inches wide placed across the center of the specimen and at right angles to its length (fig. 27). Hence the plate covers one-third of the surface. The standard placement is with the growth rings vertical. The rate of descent of the movable head of the testing machine is 0.024 inch per minute. Simultaneous readings of load and compression are taken until the test is discontinued at 0.1-inch compression. The principal property determined is the stress at proportional limit. Figure 25 is a sample data sheet and figure 26 a sample computation card for compression-perpendicular-to-grain test.

STRESS AT PROPORTIONAL LIMIT

Figure 25 illustrates a load compression curve. The proportional limit is located as indicated from the straight-line portion of the curve. From formula 18, (p. 98), the stress at proportional limit for the test specimen represented by figure 25 is

$$S_{PL}=\frac{2000}{2\times 2.01}=498 \text{ pounds per square inch}$$

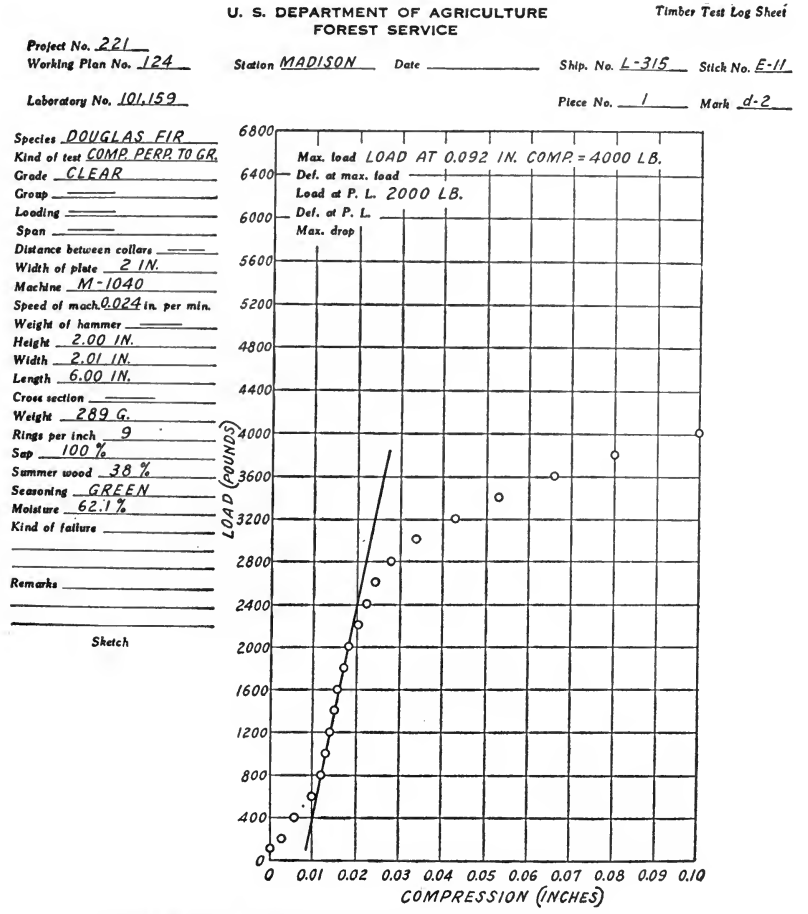


FIGURE 26.—Data sheet for compression-perpendicular-to-grain test.

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Form 509
(Revised January,)

COMPRESSION AT RIGHT ANGLES TO GRAIN

L-315 (Ship. No.) F-11 (Stick No.) 101159 (Lab. No.)

1 (Piece No.) d-2 (Mark) Station MADISON Date AUG. 20 124 (Project No.)

Species DOUGLAS FIR Grade CLEAR Seasoning GREEN

Rings 9 Sap 100 % Summer wood 38 % Moisture 62.1 %

Width of plate 2 IN. Length 6.00 IN. Height 2.00 IN. Width 2.01 IN. Weight 289 G.

Specific Gravity		Load at P. L.	Crush. St. at P. L.	$\Delta \div h$	
At Test.	Ov. Dry				
0.732	0.452	2000	498		

FIGURE 27.—Sample computation card for compression-perpendicular-to-grain test.

HARDNESS

Hardness is measured by the load required to embed a 0.444-inch ball (fig. 28) to one-half its diameter in the wood. (The diameter of the ball is such that its projected area is 1 square centimeter). The rate of penetration of the ball is 0.25 inch per minute. Two penetrations are made on each end, two on a radial, and two on a tangential surface of the wood. A special tool makes it easy to determine when the proper penetration of the ball has been reached. The accompanying load is recorded as the hardness value (fig. 29).

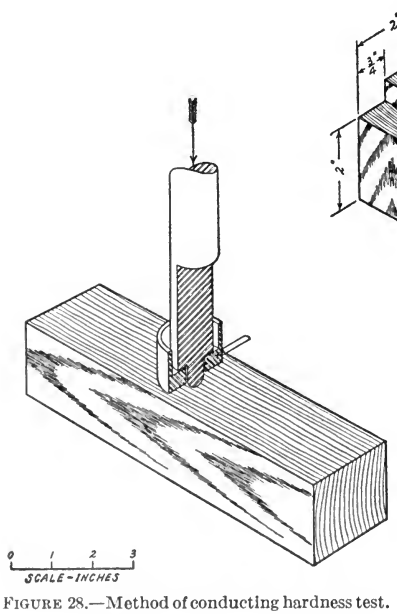

FIGURE 28.—Method of conducting hardness test.

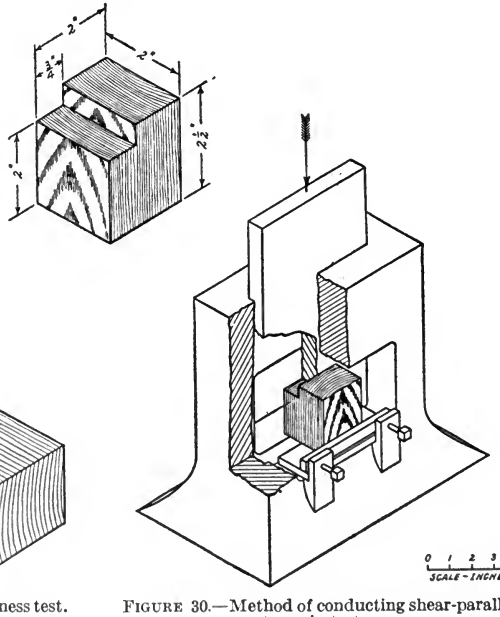

FIGURE 30.—Method of conducting shear-parallel-to-grain test.

SHEAR PARALLEL TO GRAIN

The shearing-parallel-to-grain test is made by applying force to a 2- by 2-inch lip projecting three-fourths of an inch from the side of a block 2½ inches long (fig. 30). The block is placed in a special tool having a plate that is seated on the lip and moved downward at a rate of 0.015 inch per minute. The specimen is supported at the base so that a ⅛-inch off-set exists between the outer edge of the support and the inner surface of the plate. The improved shear tool has

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Form 501 (Revised Dec. 30,)

HARDNESS

L-315 (Ship. No.) E-10 (Stick No.) 101170 (Lab. No.)

1 (Piece No.) d-4 (Mark) Station MADISON Date AUG. 20, 124 (Project No.)

Species DOUGLAS FIR Grade CLEAR Seasoning GREEN

Rings 8 Sap ——— % Summer wood 33 % Moisture 31.7 %

Length 6.01 IN. Cross section 2.00 IN. x 2.00 IN. Weight 246 G.

	Specific Gravity.		Radial Surface.	Tangential Surface.	End Surface.
	At Test.	Ov. Dry.			
1	0.622	0.472	460	570	525
2			520	460	500
3					510
4					510
Avg.,			490	515	511

Avg. Rad. and Tang., 502

Sketch.

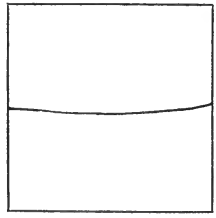

FIGURE 29.—Sample computation card for hardness test.

roller guides to reduce the friction of the plate, and an adjustable seat in the plate to insure uniform lateral distribution of the load.

Specimens are cut so that a radial surface of failure is obtained in some and a tangential surface of failure in others. The property obtained from the shear parallel-to-grain test is the maximum shearing strength.

MAXIMUM SHEARING STRENGTH

The maximum load required to shear off the lip of the specimen is recorded in the test. From formula 19, (p. 99) the maximum shear strength for the test specimen represented by figure 31 is

$$S_S = \frac{3600}{2.02 \times 2.01} = 887 \text{ pounds per square inch}$$

Form 510 (Revised Dec.,)

TANGENTIAL SHEAR

L-315 (Ship. No.) E-12 (Stick No.) 101183 (Lab. No.)

1 (Piece No.) C-5 (Mark) Station MADISON Date AUG. 21, 124 (Project No.)

Species DOUGLAS FIR Grade CLEAR Seasoning GREEN

Rings 8 Sap 75 % Summer wood 30 % Moisture 80.0 %

Shearing Area	Max. Load	Shearing Str.	Time		Sketch
2.02 x 2.01	3600	887			

FIGURE 31.—Sample computation card for shear-parallel-to-grain test.

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CLEAVAGE

The cleavage test is made to determine the resistance of wood to forces that produce a splitting action. The specimen is 2 by 2 inches in cross section, and 3¾ inches in overall length, with a cleavage section 3 inches long. The forces are applied with special grips as shown in figure 32, the rate of motion of the movable head of the testing machine being 0.25 inch per minute. Tests are made on some specimens cut so as to give a radial surface of failure, and on others cut to give a tangential surface of failure. The value obtained from the cleavage test is the load to cause splitting.

The maximum load causing failure of the specimen is observed. From formula 20 (p. 99), the load to cause splitting, for the specimen represented by figure 33, is

$$S_{CL}=\frac{365}{2.01}=182 \text{ pounds per inch of width.}$$

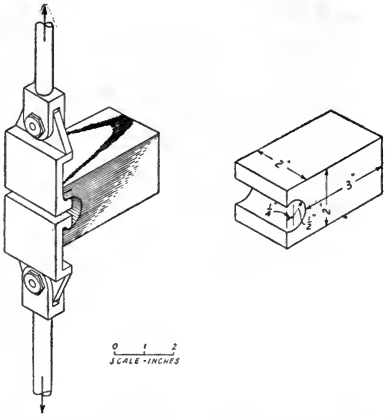


FIGURE 32.—Method of conducting cleavage test.

Form 502 (Revised Dec.,)

R CLEAVAGE

(Ship. No.)	(Stick No.)	(Lab. No.)
I-315	E-12	101177

(Piece No.)	(Mark)	Station	(Project No.)
1	C-3	MADISON	124

Date AUG. 21

Species DOUGLAS FIR Grade CLEAR Seasoning GREEN

Rings 8 Sap 75 % Summer wood 30 % Moisture 31.6 %

Height.	Width.	Length.	Max. Load.	Load per Inch Width.
	2.01	2.98	365	182

Sketch.

8—1433

FIGURE 33.—Sample computation card for cleavage test.

TENSION PERPENDICULAR TO GRAIN

The tension-perpendicular-to-grain test is made to determine the resistance of wood across the grain to slowly applied loads. The test specimen is 2 by 2 inches in cross section, and 2½ inches in over-all length, with a length at mid-height of 1 inch. The load is applied with the special grips shown in figure 34, the rate of motion of the movable head of the testing machine being 0.25 inch per minute. Some specimens are cut to give a radial, and others to give a tangential surface of failure.

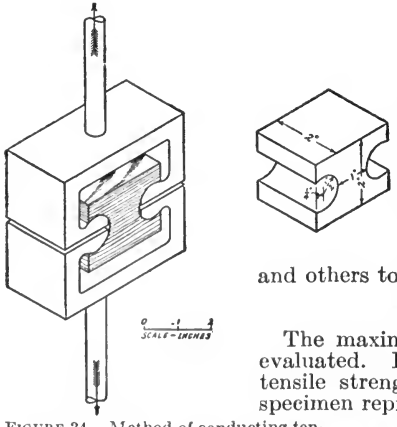


FIGURE 34.—Method of conducting tension-perpendicular-to-grain test.

MAXIMUM TENSILE STRENGTH

The maximum tensile strength is the only property evaluated. From formula 21 (p. 99) the maximum tensile strength (perpendicular to the grain) for the specimen represented by figure 35 is

$$S_{TP}=\frac{533}{2.01\times 0.97}=273 \text{ pounds per square inch.}$$

Form 511 (Revised Dec.,) R TENSION PERPENDICULAR TO GRAIN

L-315 (Ship. No.) E-12 (Stick No.) 101189 (Lab. No.)

1 (Piece No.) C-6 (Mark) Station MADISON Date AUG. 21, 124 (Project No.)

Species DOUGLAS FIR Grade CLEAR Seasoning GREEN

Rings 8 Sap 80 % Summer wood 30 % Moisture 44.2 %

Height.	Width.	Length.	Maximum Load.	Tension. Lbs. per sq. in.
	2.01	0.97	533	273

Sketch.

FIGURE 35.—Sample computation card for tension-perpendicular-to-grain test.

TENSION PARALLEL TO GRAIN

The tension-parallel-to-grain test is made to determine the resistance of wood to slowly applied loads acting along the grain. The test specimen is 30 inches long (fig. 1). The specimen is supported by the shoulders near the ends. The rate of motion of the movable head of the testing machine is 0.05 inch per minute. Simultaneous readings of load and of deformation over a 2-inch or 4-inch gage length are taken when it is desired to determine modulus of elasticity.

MAXIMUM TENSILE STRENGTH

From formula 22 (p. 99), the maximum tensile strength parallel to the grain for the specimen represented by figure 36 is

$$S_{TPA}=\frac{2,085}{0.485\times 0.482}=8,920 \text{ pounds per square inch.}$$

Form 511-B TENSION PARALLEL TO GRAIN

1326 (Ship. No.) L-3 (Stick No.) 632170 (Lab. No.)

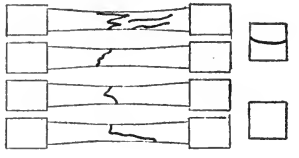
6 (Piece No.) a (Mark) Station MADISON Date 124 (Project No.)

Species LOBLOLLY PINE Grade CLEAR Seasoning GREEN

Rings 6 Sap 100 % Summer wood 35 % Moisture 29.3 %

Cross Section	Length	Maximum Load	Tension Lbs. per sq. in.
0.485" x 0.482"		2085	8920

Sketch



FAILURE: SPLINTERING TENSION

FIGURE 36.—Sample computation card for tension-parallel-to-grain test.

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LINEAR SHRINKAGE

Shrinkage measurements are made to determine the change in dimension with change in moisture content. The test specimen is 1 inch thick, 4 inches wide, and 1 inch in length along the grain. Two specimens are taken from each tree, one for measuring radial shrinkage, the other tangential. The width is measured in the apparatus shown in figure 37, which employs a micrometer reading to 0.001

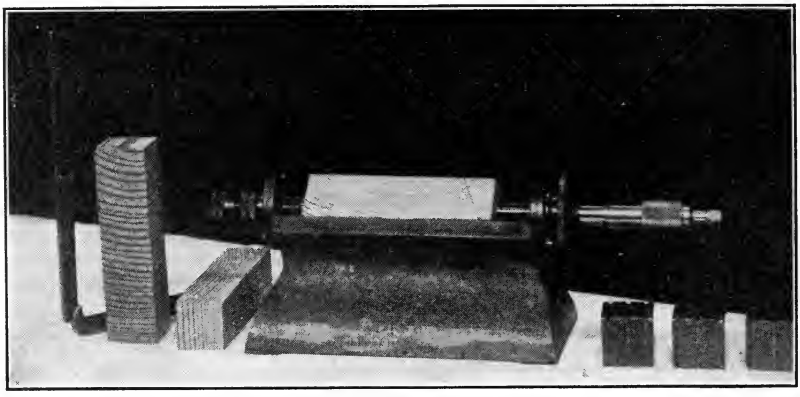

FIGURE 37.—Method of measuring linear shrinkage.

inch. The width of the specimens is measured when green, and after oven drying. In some instances measurements are also taken at intermediate stages of drying.

The linear skrinkage from the green to the oven-dry condition is the original width minus the width when oven-dry, divided by the original width. This ratio is expressed as a percentage.

From formula 23 (p. 99), the radial shrinkage for the specimen represented by figure 38 is

$$F_R = \frac{4.006 - 3.808}{4.006} \times 100 = 4.9 \text{ percent.}$$

Form 541

SHRINKAGE—RADIAL AND TANGENTIAL

L-315 (SHIP NO.) ____ (STICK NO.) 101 200 / 101 199 (LAB. NOS.)

1 (PIECE NO.) d (MARK) STATION—MADISON, WIS. 124 (PROJECT NO.)

SPECIES DOUGLAS FIR

NOMINAL SIZE OF SPECIMEN 1 IN. X 4 IN. X 1 IN.

SEASONING	DATE	RINGS PER INCH	% SAP	% SUMMER WOOD	WIDTH INCHES	WEIGHT GRAMS	% MOISTURE	X % SHRINKAGE
RADIAL								
GREEN	AUG. 19,	11	30	41	4.006	49.8	66.5	
OVEN-DRY	OCT. 5,				3.808	29.9		4.9
TANGENTIAL								
GREEN	AUG. 19,	12	95	34	4.016	64.0	119.1	
OVEN-DRY	OCT. 5,				3.632	29.2		9.5

X BASED ON GREEN WIDTH

FIGURE 38.—Sample computation card for linear shrinkage measurements.

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SHRINKAGE IN VOLUME

Shrinkage-in-volume determinations are made on specimens 2 by 2 inches cross section and 6 inches long. Volume measurements are made by an immersion method (fig. 39). The specimens when oven dry are dipped in hot paraffin before immersion to prevent the absorption of moisture, the oven-dry weight being taken before the paraffin is applied. These final measurements afford data for computing specific gravity based on volume when oven dry.

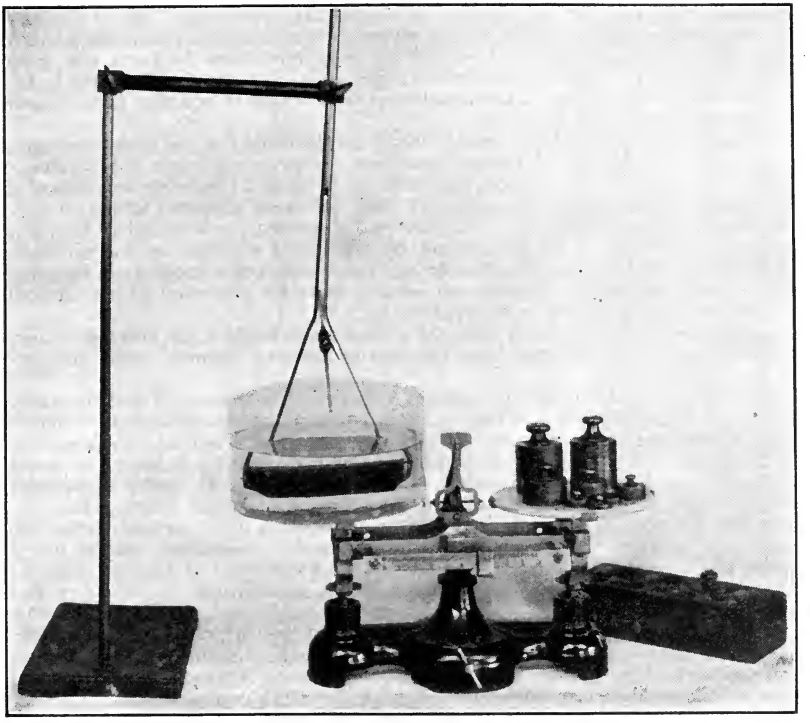

FIGURE 39.—Method of determining volume by means of immersion.

Form 554 (Rev. July,)

SPECIFIC GRAVITY AND VOLUMETRIC SHRINKAGE

L-315 (SHIP. NO.) S-6 (STICK NO.) 101197 (LAB. NO.)

1 (PIECE NO.) d-8 (MARK) STATION, Madison AUG. 20, (DATE) 124 (PROJECT NO.)

SPECIES DOUGLAS FIR

NOMINAL SIZE OF SPECIMEN 2 IN. X 2 IN. X 6 IN. % SAP 0 % SUMMER WOOD 40

	DATE	RINGS PER INCH	WEIGHT, GRAMS	% MOIST	VOLUME C. C.	SPECIFIC GRAVITY	WEIGHT, LBS. PER CU. FT.	X % VOL. SHRINKAGE
GREEN	AUG. 20,	8	253	33.2	398	0.477	39.6	13.8
AIR DRY								
KILN DRY								
OVEN DRY	SEP. 25,		190		343	0.554	34.5	

X BASED ON ORIGINAL VOLUME (GREEN, AIR-DRY, KILN-DRY)

NOTE—USE BACK OF CARD FOR CARBON IMPRESSIONS

1ST WT. ----------

2D WT. ----------

REMARKS: ---------- VOL. ----------

FIGURE 40.—Sample computation card for specific gravity and volumetric shrinkage determinations.

From formula 24 (p. 99), the shrinkage in volume for the specimen represented by figure 40 is

$$F_B=\frac{398-343}{398}\times 100=13.8 \text{ percent.}$$

STRENGTH AND RELATED PROPERTIES, BY LOCALITIES, OF WOODS GROWN IN THE UNITED STATES

In table 1 only average values for each species are presented. Table 21 records the average values, by localities, of the several lots of material comprising the test specimens for each species. These values were combined to form the species averages of table 1. In forming the averages given in table 1 each value in table 21 was weighted according to the number of trees listed in column 5 on the line with "green" in column 4.

The values given in table 21 for dry material are those for the moisture content prevailing in the material at time of test, and comprise the basic data. Because of differences in moisture content, values given in table 21 for different lots of dry material are not directly comparable but those for green material afford an opportunity for comparing localities. With the aid of the data on variability previously presented and discussed (p. 17), it can be estimated whether or not differences among localities with respect to the strength properties of a species are significant and thus can be decided whether one locality is to be preferred as a source of a supply of the species under consideration.

Important features in which table 21 differs from table 1 are the following:

1. The data in each pair of lines represents material from a single county or other local subdivision.

2. For "dry" wood the specific-gravity value given in column 9 and the various strength values listed have not been adjusted to a moisture content of 12 percent as have the corresponding figures in table 1 but are the actual values as found from the tests. The values of moisture content in column 8 apply to specific gravity (column 9) and to the values in columns 24 and 25 under compression parallel to grain. The actual value of moisture content at which other tests were made differs only slightly, usually by a fraction of a percent, from those given in column 8. As may be noted, the moisture-content values for dry material vary over a considerable range. This variability is for the most part due to variations in the conditions under which the various groups of material were dried. These moisture-content values are accordingly not those to which the various species or groups of material would be dried by any one set of drying conditions. Under continued exposure to an unchanging combination of temperature and relative humidity wood reaches a fixed moisture content known as the equilibrium moisture content for that combination. Values of equilibrium moisture content vary only slightly among different species.

NOMENCLATURE OF COMMERCIAL WOODS

The names of lumber used by the trade are not always identical with those adopted as official by the Forest Service. Where the names are not identical some confusion may result. Table 22 has therefore been prepared to show the standard commercial names for softwood lumber as prescribed in American lumber standards and the hardwood lumber names current in the trade together with the corresponding botanical names and official Forest Service names used in this bulletin.

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TABLE 22.—*Nomenclature of commercial woods*

Commercial name	Botanical name	Forest Service name used in this bulletin
HARDWOODS		
Red alder	*Alnus rubra*	Red alder.
	Alnus rhombifolia	White alder.
White ash	*Fraxinus americana*	White ash.
	Fraxinus biltmoreana	Biltmore white ash.
	Fraxinus pennsylvanica lanceolata	Green ash.
	Fraxinus pennsylvanica	Red ash.
	Fraxinus quadrangulata	Blue ash.
Black ash	*Fraxinus nigra*	Black ash.
Oregon ash	*Fraxinus oregona*	Oregon ash.
Aspen	*Populus tremuloides*	Aspen.
	Populus grandidentata	Largetooth aspen.
Basswood	*Tilia glabra*	Basswood.
	Tilia heterophylla	White basswood.
Beech	*Fagus grandifolia*	Beech.
Birch	*Betula lutea*	Yellow birch.
	Betula lenta	Sweet birch.
	Betula nigra	River birch.
Paper birch	*Betula papyrifera*	Paper birch.
	Betula populifolia	Gray birch.
Alaska birch	*Betula kenaica*	Kenai birch.
Buckeye	*Aesculus octandra*	Yellow buckeye.
	Aesculus glabra	Ohio buckeye.
Butternut	*Juglans cinerea*	Butternut.
Catalpa	*Catalpa speciosa*	Hardy catalpa.
Cherry	*Prunus serotina*	Black cherry.
Chestnut	*Castanea dentata*	Chestnut.
	Castanea pumila	Chinquapin.
Chinquapin	*Castanopsis chrysophylla*	Golden chinquapin.
Black cottonwood	*Populus trichocarpa*	Black cottonwood.
	Populus trichocarpa hastata	Northern black cottonwood.
	Populus macdougalii	Macdougal cottonwood.
	Populus fremontii	Cottonwood.
Cottonwood	*Populus deltoides virginiana*	Southern cottonwood.
	Populus heterophylla	Swamp cottonwood.
	Populus balsamifera	Balsam poplar.
	Populus deltoides	Eastern cottonwood.
	Populus sargentii	Cottonwood.
Cucumber	*Magnolia acuminata*	Cucumber magnolia.
Dogwood	*Cornus florida*	Dogwood.
Pacific dogwood	*Cornus nuttallii*	Pacific dogwood.
Rock elm	*Ulmus racemosa*	Rock elm.
Soft elm	*Ulmus americana*	American elm.
	Ulmus fulva	Slippery elm.
Black gum	*Nyssa sylvatica*	Black gum.
	Nyssa biflora	Swamp black gum.
Red gum (heartwood only)	*Liquidambar styraciflua*	Red gum.
Sap gum (sapwood only)	*Liquidamber styraciflua*	Do.
Hackberry	*Celtis occidentalis*	Hackberry.
	Celtis laevigata	Sugarberry.
Hickory	*Hicoria ovata*	Shagbark hickory.
	Hicoria laciniosa	Bigleaf shagbark hickory.
	Hicoria alba	Mockernut hickory.
	Hicoria glabra	Pignut hickory.
	Hicoria cordiformis	Bitternut hickory.
	Hicoria cordiformis elongata	Do.
Holly	*Ilex opaca*	Holly.
Ironwood	*Ostrya virginiana*	Hophornbeam.
Black ironwood	*Krugiodendron ferreum*	Black ironwood.
Black locust	*Robinia pseudoacacia*	Black locust.
Honeylocust	*Gleditsia triacanthos*	Honeylocust.
Madrono	*Arbutus menziesii*	Pacific madrone.
Magnolia	*Magnolia grandiflora*	Evergreen magnolia.
Hard maple	*Acer saccharum*	Sugar maple.
	Acer nigrum	Black maple.
Soft maple	*Acer saccharinum*	Silver maple.
	Acer rubrum	Red maple.
White maple (unstained sapwood)	*Acer saccharum*	Sugar maple.
Oregon maple	*Acer macrophyllum*	Bigleaf maple.
Red oak	*Quercus borealis maxima*	Red oak.
	Quercus borealis	Do.
	Quercus velutina	Black oak.
	Quercus shumardii	Shumard red oak.
	Quercus texana	Texas red oak.
	Quercus palustris	Pin oak.
	Quercus phellos	Willow oak.
	Quercus laurifolia	Laurel oak.
	Quercus rubra	Southern red oak.
	Quercus rubra pagodaefolia	Swamp red oak.
	Quercus nigra	Water oak.
	Quercus ellipsoidalis	Jack oak.
	Quercus coccinea	Scarlet oak.
	Quercus marilandica	Blackjack oak.

TABLE 22.—*Nomenclature of commercial woods*—Continued

Commercial name	Botanical name	Forest Service name used in this bulletin
HARDWOODS—continued		
Red oak	*Quercus kelloggii*	California black oak.
	Quercus catesbaei	Turkey oak.
White oak	*Quercus alba*	White oak.
	Quercus stellata	Post oak.
	Quercus lyrata	Overcup oak.
	Quercus bicolor	Swamp white oak.
	Quercus muehlenbergii	Chinquapin oak.
	Quercus garryana	Oregon white oak.
	Quercus prinus	Swamp chestnut oak.
	Quercus montana	Chestnut oak.
	Quercus macrocarpa	Bur oak.
	Quercus utahensis	Rocky mountain white oak.
Live oak	*Quercus wislizenii*	Highland live oak.
	Quercus agrifolia	Coast live oak.
	Quercus chrysolepis	Canyon live oak.
	Quercus virginiana	Live oak.
Osage-orange	*Toxylon pomiferum*	Osage-orange.
Pecan	*Hicora pecan*	Pecan.
	Hicora cordiformis	Bitternut hickory.
	Hicora cordiformis elongata	Do.
Persimmon	*Diospyros virginiana*	Persimmon.
Sassafras	*Sassafras variifolium*	Sassafras.
Silverbell	*Halesia carolina*	Silverbell.
Sycamore	*Platanus occidentalis*	Sycamore.
Tupelo	*Nyssa aquatica*	Tupelo gum.
Black walnut	*Juglans nigra*	Black walnut.
Willow	*Salix nigra*	Black willow.
Yellow poplar	*Liriodendron tulipifera*	Yellow poplar.
SOFTWOODS		
Alaska cedar	*Chamaecyparis nootkatensis*	Alaska cedar.
Eastern red cedar	*Juniperus virginiana*	Eastern red cedar.
	Juniperus lucayana	Southern red cedar.
	Juniperus mexicana	Mountain cedar.
Incense cedar	*Libocedrus decurrens*	Incense cedar.
Northern white cedar	*Thuja occidentalis*	Northern white cedar.
Port Orford cedar	*Chamaecyparis lawsoniana*	Port Orford cedar.
Southern white cedar	*Chamaecyparis thyoides*	Southern white cedar.
Western juniper	*Juniperus utahensis*	Utah juniper.
	Juniperus pachyphloea	Alligator juniper.
	Juniperus scopulorum	Rocky mountain red cedar.
	Juniperus occidentalis	Western juniper.
Western red cedar	*Thuja plicata*	Western red cedar.
Red cypress (coast type)	*Taxodium distichum*	Southern cypress.
Yellow cypress (inland type)	*Taxodium distichum*	Do.
White cypress (inland type)	*Taxodium distichum*	Do.
Douglas fir	*Pseudotsuga taxifolia*	Douglas fir.
Red fir (intermountain type)	*Pseudotsuga taxifolia*	Do.
Red fir (Rocky Mountain type)	*Pseudotsuga taxifolia*	Do.
Alpine fir	*Abies lasiocarpa*	Alpine fir.
	Abies arizonica	Corkbark fir.
Balsam fir	*Abies balsamea*	Balsam fir.
	Abies fraseri	Southern balsam fir.
Golden fir	*Abies magnifica*	California red fir.
Noble fir	*Abies nobilis*	Noble fir.
Silver fir	*Abies amabilis*	Silver fir.
White fir	*Abies concolor*	White fir.
	Abies grandis	Lowland white fir.
Eastern hemlock	*Tsuga canadensis*	Eastern hemlock.
	Tsuga caroliniana	Carolina hemlock.
Mountain hemlock	*Tsuga mertensiana*	Mountain hemlock.
West coast hemlock	*Tsuga heterophylla*	Western hemlock.
Western larch	*Larix occidentalis*	Western larch.
Arkansas soft pine	*Pinus echinata*	Shortleaf pine.
	Pinus taeda	Loblolly pine.
Idaho white pine	*Pinus monticola*	Western white pine.
Jack pine	*Pinus banksiana*	Jack pine.
Loblolly pine	*Pinus taeda*	Loblolly pine.
Lodgepole pine	*Pinus contorta*	Lodgepole pine.
Longleaf pine	*Pinus palustris*	Longleaf pine.
North Carolina pine	*Pinus taeda*	Loblolly pine.
	Pinus echinata	Shortleaf pine.
	Pinus virginiana	Virginia pine.
	Pinus strobus	Northern white pine.
Norway pine	*Pinus resinosa*	Norway pine.
Pond pine	*Pinus rigida serotina*	Pond pine.
Ponderosa pine	*Pinus ponderosa*	Ponderosa pine.
Pondosa pine	*Pinus ponderosa*	Do.

TABLE 22.—*Nomenclature of commercial woods*—Continued

Commercial name	Botanical name	Forest Service name used in this bulletin
SOFTWOODS—continued		
Shortleaf pine	*Pinus echinata*	Shortleaf pine.
Slash pine	*Pinus caribaea*	Slash pine.
Southern pine	*Pinus taeda*	Loblolly pine.
	Pinus palustris	Longleaf pine.
	Pinus rigida serotina	Pond pine.
	Pinus echinata	Shortleaf pine.
	Pinus caribaea	Slash pine.
	Pinus rigida	Pitch pine.
	Pinus glabra	Spruce pine.
Sugar pine	*Pinus lambertiana*	Sugar pine.
Redwood	*Sequoia sempervirens*	Redwood.
Eastern spruce	*Picea mariana*	Black spruce.
	Picea rubra	Red spruce.
	Picea glauca	White spruce.
Engelmann spruce	*Picea engelmannii*	Engelmann spruce.
	Picea pungens	Blue spruce.
Sitka spruce	*Picea sitchensis*	Sitka spruce.
Tamarack	*Larix laricina*	Tamarack.
Pacific yew	*Taxus brevifolia*	Pacific yew.

FORMULAS USED IN COMPUTING

LEGEND

S_{CL} = strength in cleavage, pounds per inch of width.
S_{PL} = stress at proportional limit, pounds per square inch.
S_{TP} = stress in tension perpendicular to grain, pounds per square inch.
S_{TPA} = stress in tension parallel to grain, pounds per square inch.
P' = load at proportional limit, pounds.
P = maximum load, pounds.
R = modulus of rupture, pounds per square inch.
S_s = shear stress, pounds per square inch.
M = bending moment, in inch-pounds.
S = computed unit stress, pounds per square inch.

I = moment of inertia, inches^4 $\left(\text{for a rectangular beam } I=\frac{b\times d^3}{12}\right)$.

c = distance from neutral axis of beam to extreme fiber, inches.
V = total vertical shear at any cross section of a beam, pounds.
L = length, inches; in static bending, L = span, inches.
b = breadth, inches.
d = depth, inches.
y = deflection, inches.
b_1 = width of specimen when green, inches.
b_2 = width of specimen when oven-dry, inches.
K_1 = volume of specimen when green, cubic inches.
K_2 = volume of specimen when oven-dry, cubic inches.
G = specific gravity.
W = work, inch-pounds per cubic inch.
W_{PL} = work to proportional limit, inch-pounds per cubic inch.
W_{ML} = work to maximum load, inch-pounds per cubic inch.
W_T = total work, inch-pounds per cubic inch.
E = modulus of elasticity, pounds per square inch.
A = area under direct stress, square inches.
H = head or total drop of hammer, plus impact deflection, inches.
W = weight of hammer, impact bending test, pounds.
Δ = impact deflection plus static deflection (0.01 inch).
F_R = radial shrinkage from green to oven-dry condition.
F_T = tangential shrinkage from green to oven-dry condition.
F_V = volumetric shrinkage from green to oven-dry condition.

126695°—35——7

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BENDING (SQUARE OR RECTANGULAR BEAMS)

LOAD APPLIED AT CENTER

$$S_{PL}=\frac{3\times P'\times L}{2\times b\times d^2} \tag{1}$$

$$R=\frac{3\times P\times L}{2\times b\times d^2} \tag{2}$$

$$E=\frac{P'\times L^3}{4\times b\times d^3\times y} \tag{3}$$

$$S_s=\frac{3\times P}{4\times b\times h} \tag{4}$$

$$W_{PL}=\frac{P'y}{2\times b\times d\times L} \tag{5}$$

$$W_{ML}=\frac{\text{area under curve to maximum load in inch-pounds}}{b\times d\times L} \tag{6}$$

$$W_T=\frac{\text{total area under curve in inch-pounds}}{b\times d\times L} \tag{7}$$

UNIFORMLY DISTRIBUTED LOAD

$$S_{PL}=\frac{3\times P'\times L}{4\times b\times d^2} \tag{8}$$

$$\mathrm{R}=\frac{3\times P\times L}{4\times b\times d^2} \tag{9}$$

$$E=\frac{5\times P'\times L^3}{32\times b\times d^3\times y} \tag{10}$$

ANY LOADING

$$M=\frac{SI}{c} \qquad M_{max}=\frac{RI}{c} \tag{11}$$

$$S_s=\frac{3\times V}{2\times b\times d} \tag{12}$$

IMPACT BENDING

$$S_{PL}=\frac{3WHL}{bd^2\Delta} \tag{13}$$

$$W_{PL}=\frac{WH}{Lbh} \tag{14}$$

COMPRESSION PARALLEL TO GRAIN

$$S_{PL}=\frac{P'}{A} \tag{15}$$

$$S_c=\frac{P}{A} \tag{16}$$

$$E=\frac{P'L}{Ay} \tag{17}$$

COMPRESSION PERPENDICULAR TO GRAIN

$S_{PL}=\frac{P'}{A}$, where A=area of specimen under plate, square inches (18)

SHEAR PARALLEL TO GRAIN

$$S_s=\frac{P}{A}, \text{ where } A=\text{area under shear, square inches} \tag{19}$$

CLEAVAGE PARALLEL TO GRAIN

$$S_{CL}=\frac{P}{b} \tag{20}$$

TENSION PERPENDICULAR TO GRAIN

$$S_{TP}=\frac{P}{A} \tag{21}$$

TENSION PARALLEL TO GRAIN

$$S_{TPA}=\frac{P}{A} \tag{22}$$

LINEAR SHRINKAGE (PERCENT)

$$F_R \text{ or } F_T=\frac{b_1-b_2}{b_1}\times 100 \tag{23}$$

VOLUMETRIC SHRINKAGE (PERCENT)

$$F_V=\frac{K_1-K_2}{K_1}\times 100 \tag{24}$$

SPECIFIC GRAVITY

$$G=\frac{\text{weight in grams}}{\left(1+\frac{\text{percent moisture}}{100}\right)\times\text{volume in cubic centimeters}} \tag{25}$$

U. S. GOVERNMENT PRINTING OFFICE: 1935

Shipment no.		Impact bending			Compression parallel to grain		Compression perpendicular to grain; stress at proportional limit	Hardness; load required to embed a 0.444-inch ball to ½ its diameter		Shear parallel to grain; maximum shearing strength	Cleavage; load to cause splitting	Tension perpendicular to grain; maximum tensile strength
		Stress at proportional limit	Work to proportional limit	Height of drop causing complete failure (50-pound hammer)	Stress at proportional limit	Maximum crushing strength		End	Side			
1		21	22	23	24	25	26	27	28	29	30	31
		Lb. per sq. in.	*In.-lb. per cu. in.*	*Inches*	*Lb. per sq. in.*	*Lb. per sq. in.*	*Lb. per sq. in.*	*Pounds*	*Pounds*	*Lb. per sq. in.*	*Lb. per in. of width*	*Lb. per sq. in.*
		8,040	2.6	22	2,620	2,960	313	554	440	770	217	394
263	Ald	**13,040**	**5.9**	**20**	**5,290**	**7,050**	**651**	**1,170**	**652**	**1,210**	**284**	**431**
		7,590	3.0	33	1,990	3,000	854	1,041	1,088	1,636	476	905
746	Ap	**16,850**	**8.6**	**44**	**3,340**	**6,690**	**1,418**	**2,300**	**1,800**	**1,764**		
		11,930	4.9	30	3,530	3,980	875	953	853	1,232	343	536
257	Ash	**19,850**	**10.4**	**46**	**7,360**	**10,370**	**2,020**	**2,060**	**1,300**	**1,972**	**452**	**813**
		7,230	2.5	35	1,720	2,340	409	610	552	866	266	490
219	Ash			**44**	**6,620**	**8,190**	**1,270**	**1,338**	**994**	**1,794**	**397**	**760**
				30		2,260	452	565	490	854	292	490
5		**12,160**	**5.3**	**27**	**3,950**	**5,590**	**893**	**1,101**	**792**	**1,660**	**402**	**696**
		11,140	5.0	43	3,580	4,180	994	1,140	1,028	1,544	353	584
222	Ash	**20,550**	**10.5**	**42**	**5,940**	**7,740**	**1,911**	**1,833**	**1,356**	**2,153**	**454**	
		11,720	5.6	32	3,240	4,040	801	842	732	1,202	349	614
75	Ash	**15,850**	**7.3**	**32**	**5,180**	**7,300**	**1,232**	**1,676**	**1,153**	**1,832**	**372**	**712**
		11,150	4.4	37	3,890	4,360	1,012	1,073	1,007	1,318	345	564
223		**18,900**	**9.0**	**30**	**5,520**	**7,850**	**2,220**	**1,870**	**1,362**	**2,336**	**564**	**740**
		8,920	3.0	39	2,760	3,510	653	851	790	1,191	309	587
318	Ash	**15,000**	**6.2**	**31**	**4,610**	**7,120**	**1,998**	**1,666**	**1,296**	**2,092**	**461**	**775**
		8,760	3.7	31	2,850	3,360	989	885	752	1,214	357	574
223	Ash	**15,150**	**7.9**	**22**	**4,220**	**6,320**	**1,995**	**1,535**	**1,026**	**1,893**	**459**	**828**
		11,710	4.9	33	3,450	4,220	889	1,121	1,008	1,336	340	658
101	Ash	**14,920**	**6.5**	**34**	**6,240**	**7,900**	**1,315**	**2,065**	**1,416**	**2,215**	**588**	**868**
		13,780	5.9	47	3,960	4,610	794	1,145	1,083	1,604	440	787
214	Ash	**23,840**	**12.8**	**46**	**8,080**	**9,420**	**2,090**	**2,240**	**1,680**	**2,525**	**471**	**1,128**
		11,620	5.1	38	2,870	3,390	705	872	785	1,183	336	590
256	Ash	**19,050**	**11.0**	**37**	**5,540**	**8,480**	**1,762**	**1,833**	**1,224**	**2,008**	**310**	**897**
		16,780	6.9	35	2,750	3,840	842	940	968	1,392	258	430
904	Ash	**13,280**	**7.2**	**50**	**5,720**	**7,520**	**1,364**	**1,635**	**1,312**	**1,877**	**556**	**1,080**
		6,880	2.5	28	1,600	2,160	203	266	318	625	116	182
300	Ash	**10,470**	**4.0**	**24**	**4,320**	**6,440**	**552**	**848**	**420**	**890**	**224**	**380**
		7,010	2.8	18	1,720	2,130	239	289	286	683	152	276
465		**9,680**	**3.6**	**18**		**5,520**	**718**	**567**	**338**	**1,023**		**239**
		7,600	2.7	18	2,210	2,720	269	443	366	813	216	394
211	Ash	**15,160**	**7.0**	**27**	**5,100**	**7,080**	**646**	**710**	**462**	**1,305**	**236**	**380**
		7,220	2.3	19	1,830	2,280	239	352	374	651	164	230
904	Ash	**9,990**	**3.9**	**20**	**3,960**	**4,930**	**596**	**643**	**402**	**974**	**216**	**406**
		5,760	2.0	15	1,180	1,830	191	283	220	554	146	286
165	Bal	**6,390**	**1.8**	**8**	**3,420**	**4,800**	**540**	**461**	**364**	**1,432**	**278**	**406**
		6,590	2.1	17	2,000	2,450	221	292	263	626	149	282
197		**14,360**	**6.3**	**21**	**5,760**	**6,700**	**591**	**672**	**508**	**1,074**	**260**	**360**
		11,760	5.1	43	2,750	3,480	605	1,012	908	1,264	433	801
111	Bel	**17,200**	**8.1**	**40**	**4,020**	**6,450**	**1,185**	**1,463**	**1,217**	**1,908**	**566**	**1,140**
		9,130	3.3	38	2,300	3,080	609	891	740	1,156	395	714
197		**20,150**	**10.3**	**30**	**5,820**	**8,350**	**1,504**	**1,341**	**1,168**	**2,032**	**460**	**642**
		13,030	4.8	46	2,590	3,940	765	996	886	1,398	397	666
904	Bel	**13,430**	**4.7**	**49**	**5,470**	**8,000**	**1,278**	**1,952**	**1,552**	**2,206**	**454**	**1,192**
		10,080	4.0	106	1,420	2,670	733	895	940	1,164	256	350
904	Bel	**10,270**	**4.3**		**2,950**	**5,100**	**1,635**	**1,531**	**1,676**	**2,251**	**584**	
		9,800	3.7	37	2,050	3,030	434	553	564	917	176	196
939	Bir	**14,020**	**4.9**	**41**	**5,720**	**8,030**	**877**	**896**	**866**	**1,489**	**400**	**766**
		7,380	2.6	59	1,080	1,860	249	435	482			
865	Bir	**10,270**	**3.5**	**35**	**2,750**	**5,030**	**1,050**	**736**	**826**	**1,338**	**374**	
		7,780	2.7	45	1,640	2,210	304	400	486	786	239	382
300	Bir	**13,840**	**6.6**	**24**	**6,140**	**9,470**	**912**	**1,487**	**1,278**	**1,627**		
		8,320	2.6	53	1,630	2,510	370	532	632	886	181	
865		**13,320**	**4.8**	**48**	**3,620**	**6,140**	**1,002**	**928**	**996**	**1,214**	**444**	
		9,540	3.1	44	2,560	3,560	525	1,023	894	1,220	337	552
197	Bir	**26,700**	**13.2**	**48**	**6,680**	**10,680**	**1,750**	**2,090**	**1,486**	**2,680**	**494**	
		11,550	3.2	52	2,810	3,930	643	1,125	1,040	1,270	257	317
865				**48**	**6,120**	**7,470**	**1,132**	**1,868**	**1,469**	**2,016**	**550**	**852**
		11,080	3.8	36	2,540	3,400	439	827	754	1,146	290	486
165	Bir	**18,300**	**8.2**	**53**	**7,160**	**9,560**	**1,340**	**1,542**	**1,280**	**1,428**	**490**	**1,112**
		12,240	5.2	44	3,240	3,520	469	808	736	1,084	316	470
197		**24,000**	**11.7**	**63**	**8,620**	**9,950**	**1,480**	**1,642**	**1,350**	**2,326**	**474**	**672**
		11,220	4.2	59	2,240	3,260	633	810	822	1,094	220	352
904	Bir	**13,800**	**4.7**	**54**	**5,200**	**8,080**	**1,228**	**1,586**	**1,352**	**2,170**	**630**	**1,050**
		15,870	6.8	42	3,760	4,940	1,869	1,568	1,703	1,373	278	662
752	Bl					**8,200**	**2,390**					
		6,510	2.1	18	1,680	2,050	210	357	286	662	181	319
226	Bu	**12,720**	**6.4**	**14**	**4,000**	**5,870**	**640**	**552**	**396**	**1,142**	**268**	**660**

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Shipment no.	Impact bending			Compression parallel to grain		Compression perpendicular to grain; stress at proportional limit	Hardness; load required to embed a 0.444-inch ball to ½ its diameter		Shear parallel to grain; maximum shearing strength	Cleavage; load to cause splitting	Tension perpendicular to grain; maximum tensile strength
	Stress at proportional limit	Work to proportional limit	Height of drop causing complete failure (50-pound hammer)	Stress at proportional limit	Maximum crushing strength		End	Side			
1	21	22	23	24	25	26	27	28	29	30	31
	Lb. per sq. in.	*In.-lb. per cu. in.*	*Inches*	*Lb. per sq. in.*	*Lb. per sq. in.*	*Lb. per sq. in*	*Pounds*	*Pounds*	*Lb. per sq. in.*	*Lb. per in. of width*	*Lb. per sq. in.*
752	**18,430**	**6.6**	**26**	3,750 **4,970**	5,330 **9,620**	1,700					
211	6,990	2.3	21	2,130	2,580	258	414	394	762	225	419
226	**13,840**	**6.8**	**21**	**5,680**	**7,180**	**764**	**621**	**514**	**1,417**	**227**	**401**
752	7,700	2.7	26	1,910	2,250	287	400	379	750	225	443
318	**11,960**	**4.7**	**26**	**5,240**	**6,180**	**749**	**677**	**542**	**1,312**	**200**	**472**
1054	14,060	6.8	40	3,050	4,110 **7,560**	1,139 **1,549**	1,079	1,111	1,222	366	471
1054	8,690	3.6	58	1,890	3,270	670	679	731	1,152	260	514
197	**11,250**	**5.4**	**16**	**5,180**	**9,190**	**2,000**	**1,792**	**1,281**	**1,989**		
226	7,360	3.2	31	1,440	2,280	284	404	398	649	206	404
245	**11,470**	**4.6**	**25**	**2,460**	**4,990**	**568**	**659**	**520**	**1,142**	**286**	**585**
318	7,730	3.0	42	1,480	2,530	377	443	432	738	258	472
368	**10,560**	**4.1**	**32**	**3,560**	**5,590**	**572**	**648**	**626**	**1,156**	**326**	**570**
263	10,180	4.1	33	2,940	3,540	444	754	664	1,127	330	574
226	**14,780**	**5.9**	**28**	**7,030**	**8,370**	**1,024**	**1,690**	**1,030**	**1,928**	**354**	**558**
226	6,580	2.1	22	1,810	2,170	265	435	386	678	174	296
226	**12,100**	**5.2**	**36**	**5,520**	**6,490**	**700**	**930**	**579**	**1,241**	**261**	**338**
245	7,870	3.0	24	1,890	2,230	366	493	402	749	234	398
318	**11,800**	**6.0**	**19**	**4,380**	**6,440**	**820**	**780**	**546**	**1,192**	**260**	**481**
368	8,000	2.6	23	2,260	2,710	400	571	448	845	246	471
263	**11,280**	**4.7**	**18**	**4,560**	**6,800**	**1,032**	**773**	**612**	**1,138**	**238**	**450**
226	8,820	3.4	31	2,030	3,020	491	733	602	1,014	234	477
211	**12,520**	**6.0**	**29**	**6,380**	**7,970**	**859**	**924**	**834**	**1,454**		
197	7,150	2.3	21	1,740	2,280	242	383	344	682	222	408
534	**7,460**	**2.4**	**19**	**5,320**	**7,830**	**734**	**744**	**484**	**1,116**	**313**	**698**
5	6,820	2.2	20	1,760	2,160	204	277	253	602	170	274
5	**10,860**	**4.4**	**22**	**3,920**	**5,440**	**457**	**666**	**386**	**1,156**	**234**	**344**
300	7,090	3.5	58		3,640	1,033	1,413	1,408	1,516		
111	**19,320**	**10.1**	**40**	**6,040**	**10,200**	**2,466**	**2,983**	**2,532**		**635**	
211	9,820	3.6	56	2,410	3,640	872	1,140	979	1,298	335	736
752	**10,900**	**3.8**	**26**	**5,930**	**11,310**	**2,468**	**2,510**	**1,644**	**2,056**	**470**	
226	7,980	2.9	38	2,380	3,040	519	758	718	1,092	318	562
294	**12,130**	**6.9**	**30**	**5,190**	**6,990**	**980**	**917**	**905**			
368			34		2,700	292	536	486	825		578
263	**14,620**	**7.4**	**35**	**4,040**	**5,840**	**727**	**892**	**679**	**1,447**	**321**	**644**
226	8,120	2.9	34	2,260	2,920	410	625	546	922	310	558
211	**17,000**	**10.4**	**46**	**5,420**	**7,050**	**874**	**1,307**	**914**	**1,802**	**349**	**605**
752	8,830	3.0	42	1,630	2,930	486	743	708	1,098	353	626
752	**13,400**	**6.5**	**35**	**4,020**	**5,680**	**1,208**	**1,202**	**892**	**1,664**	**389**	**756**
226		5.0	48		3,740	693	954	898	1,270		
294	**18,310**	**9.0**	**52**	**4,900**	**7,570**	**1,603**	**1,593**	**1,257**	**2,154**	**518**	**1,068**
368	10,950	4.1	59	3,000	3,820	813	1,013	988	1,276	406	662
263	**18,700**	**9.8**	**60**	**5,700**	**9,280**	**2,109**	**1,861**	**1,686**	**2,128**	**332**	**410**
211	11,700	4.9	40	3,450	3,990	730	919	722	1,186	412	798
211	**16,590**	**8.5**	**40**	**5,240**	**7,080**	**1,145**	**1,631**	**1,214**	**2,090**	**544**	**967**
211	8,640	3.1	48	2,660	3,180	468	715	653	1,090	373	614
211	**17,980**	**9.6**	**46**	**5,740**	**7,950**	**1,254**	**1,144**	**836**	**1,754**	**294**	**398**
752					2,630 **4,910**	646	615	582			
226	9,810	4.0	30	2,490	3,040	599	786	642	1,098	334	574
294	**17,120**	**9.1**	**19**	**3,960**	**7,000**	**1,500**	**1,380**	**854**	**1,456**	**338**	**474**
368	14,150	4.7	40	4,840	5,250	1,019	1,311	1,344	1,546	362	645
368	**25,200**	**12.6**	**42**	**10,790**	**13,900**	**2,254**	**1,835**	**1,648**	**2,052**		
368	10,050	3.9	33	2,350	2,990	455	634	522	1,072	329	512
368	**19,300**	**10.4**	**32**	**5,570**	**6,820**	**992**	**1,014**	**725**	**1,750**	**400**	**868**
				2,110	2,690 **5,230**						
175	7,650	2.5	25	2,320	3,550	451	814	700	1,031	328	634
368	**11,030**	**4.6**	**17**	**4,040**	**5,850**	**865**	**1,244**	**847**	**1,577**	**366**	**592**
752	9,330	3.5	31	2,760	3,330	620	802	710	1,227	346	596
111	**15,400**	**8.4**	**21**	**5,600**	**8,320**	**1,668**	**1,515**	**1,012**	**1,898**	**364**	
211	5,030	2.3	13	930	1,510	288	286	226	588	166	384
211	**6,540**	**2.4**	**8**	**2,050**	**3,780**	**714**	**401**	**286**	**899**	**210**	**356**
211	10,420	4.5	62	2,760	3,310	575	829	784	1,128	429	724
211	**17,450**	**8.8**	**65**	**4,460**	**6,720**	**1,320**	**1,505**	**1,159**	**1,796**	**386**	**702**
211	7,350	2.8	45	1,930	2,520	475	740	677	1,058	331	607
211	**15,500**	**8.7**	**37**	**4,250**	**6,400**	**1,330**	**1,154**	**887**	**1,786**	**316**	**542**

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Shipment no.	Impact bending			Compression parallel to grain		Compression perpendicular to grain: stress at proportional limit	Hardness; load required to embed a 0.444-inch ball to ½ its diameter		Shear parallel to grain; maximum shearing strength	Cleavage; load to cause splitting	Tension perpendicular to grain; maximum tensile strength
	Stress at proportional limit	Work to proportional limit	Height of drop causing complete failure (50-pound hammer)	Stress at proportional limit	Maximum crushing strength		End	Side			
1	21	22	23	24	25	26	27	28	29	30	31
	Lb. per sq. in.	*In.-lb. per cu. in.*	*Inches*	*Lb. per sq. in.*	*Lb. per sq. in.*	*Lb. per sq. in.*	*Pounds*	*Pounds*	*Lb. per sq. in.*	*Lb. per in. of width*	*Lb. per sq. in.*
211					3,110	980	1,218	1,204	1,356		
	13,500	**5.5**	**20**	**4,750**	**8,420**	**1,880**	**2,270**	**1,675**			
43	14,350	7.8	130	1,820	3,260	1,000			1,212		
			100		**11,000**	**2,970**			**2,348**		
42	13,970	6.3	80	3,570	4,520	994			1,162		
	25,060	**14.5**	**70**		**8,550**	**2,386**			**2,512**		
43	15,860	8.5	66	4,330	4,570	986			1,237		
	26,540	**14.0**	**66**		**10,600**	**2,390**					
48	15,390	6.7	120	3,990	4,320	958			1,282		
	24,130	**12.0**	**96**		**10,400**	**2,719**					
42	14,670	6.8	44	3,600	4,600	1,065			1,270		
	18,860	**8.9**	**44**		**10,900**	**2,303**			**1,899**		
46				5,230	5,240						
42	12,780	6.1	54	3,620	3,980	938			1,032		
					7,960	**2,315**					
46	19,520	10.6	74	3,520	4,820	1,114			1,396		
			66		**10,200**	**2,816**			**2,482**		
42	16,610	8.7	96	3,450	4,870	1,101			1,208		
	25,600	**13.6**	**58**		**10,700**	**2,375**					
43	13,520	7.9	98	4,100	4,760	1,224			1,428		
	22,930	**9.9**	**76**		**10,110**	**2,994**			**2,708**		
48	16,270	7.8	96	4,270	4,820	1,130			1,358		
	27,480	**14.6**	**72**		**11,130**	**2,918**			**2,316**		
42	14,380	6.6	52	4,160	5,060	1,158			1,262		
	17,890	**8.1**	**48**		**10,120**	**2,197**			**2,360**		
43	12,460	5.5	100	2,840	4,360	1,080			1,421		
			74		**10,500**	**2,717**					
46	16,060	7.2	60	3,730	4,600	972			1,264		
	24,380	**11.9**	**64**		**11,200**	**2,370**			**2,390**		
48				2,780	4,370						
					9,850	**2,250**					
42	13,730	6.1	56	3,240	4,660	1,088			1,440		
			52	**6,190**	**10,140**	**2,208**					
226	8,900	4.4	51	2,050	2,640	610	858	792	1,130	362	606
	14,780	**8.5**	**27**	**4,260**	**7,820**	**1,525**	**1,770**	**1,150**	**2,055**		**742**
111	13,460	4.8	56	4,300	4,970	1,684	1,862	1,846	1,990	581	1,289
368	11,450	4.6	45	3,130	4,310	1,366	1,355	1,298	1,592	471	858
	16,950	**9.3**	**45**	**6,200**	**9,520**	**2,800**	**2,032**	**1,595**	**2,585**	**386**	**820**
300	10,580	3.5	73	2,570	3,570	733	1,157	1,170	1,374	334	450
	16,560	**7.6**	**40**	**8,890**	**11,750**	**2,303**	**3,148**	**2,394**	**2,114**		
752	15,230	6.8	50	3,310	4,480	1,601	1,319	1,436	1,748	450	
			29	**4,570**	**8,600**	**2,630**	**3,076**	**2,209**	**2,335**		
752	18,470	7.7	35	5,660	7,570	3,462					
	17,000	**5.8**	**18**	**3,960**	**9,160**	**2,980**					
319	8,280	4.1	57	1,980	3,020	801	1,015	1,003	1,272	429	776
	12,500	**6.2**	**22**	**4,950**	**8,140**	**1,930**	**1,980**	**1,460**	**2,342**	**425**	**948**
226	10,230	5.2	32		4,310	1,110	1,401	1,299	1,669		
	17,450	**9.3**	**46**	**3,820**	**7,120**	**2,422**	**2,670**	**2,175**			
226	18,270	7.9	44	6,120	6,800	1,426	1,637	1,568	1,755	400	772
	21,580	**10.1**	**59**	**6,920**	**10,880**	**2,523**	**1,572**	**1,726**	**2,714**	**326**	**620**
319	10,560	5.1	42	2,370	3,340	817	1,158	970	1,456	440	788
	9,930	**3.9**	**16**	**5,210**	**11,020**	**2,710**	**2,665**	**1,987**	**2,167**	**556**	
294	8,180	2.6	28	2,720	3,230	594	954	771	1,226	370	678
	14,360	**6.6**	**17**	**7,340**	**9,810**	**2,311**	**2,427**	**1,635**		**452**	
226	9,290	2.9	30	2,810	3,140	408	595	515	991	262	438
	17,840	**7.6**	**37**	**6,130**	**8,540**	**865**	**1,155**	**790**	**1,533**	**300**	**815**
258	8,820	3.2	54	2,160	2,700	570	785	738	1,044	344	612
	15,000	**7.5**	**25**	**3,870**	**6,600**	**1,250**	**1,482**	**1,118**	**1,703**	**464**	**982**
226	8,600	2.9	23	2,270	2,610	330	574	503	827	259	451
	16,430	**7.4**	**28**	**5,560**	**7,500**	**838**	**976**	**688**	**1,339**	**360**	**792**
752	20,520	8.2	52	5,200	6,490	2,456	2,012	2,236	1,804		
			32	**6,190**	**10,840**	**3,318**		**2,745**	**3,250**		
263	8,520	2.8	23	2,510	3,240	554	762	624	1,108	324	597
			30	**5,850**	**7,180**	**1,115**	**1,626**	**946**	**2,013**	**432**	**525**
111	10,160	3.8	48	2,800	3,270	742	936	836	1,128	429	717
	13,750	**5.8**	**39**	**4,940**	**7,390**	**1,320**	**1,836**	**1,236**	**2,030**	**420**	**667**
5			28		3,680	605	766	748	1,232	267	
	17,030	**8.5**	**31**	**5,110**	**6,610**	**1,291**	**1,531**	**1,024**	**1,789**	**476**	**809**

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Shipment no.		Impact bending			Compression parallel to grain		Compression perpendicular to grain; stress at proportional limit	Hardness; load required to embed a 0.444-inch ball to ½ its diameter		Shear parallel to grain; maximum shearing strength	Cleavage; load to cause splitting	Tension perpendicular to grain; maximum tensile strength
		Stress at proportional limit	Work to proportional limit	Height of drop causing complete failure (50-pound hammer)	Stress at proportional limit	Maximum crushing strength		End	Side			
1		21	22	23	24	25	26	27	28	29	30	31
		Lb. per sq. in.	*In.-lb. per cu. in.*	*Inches*	*Lb. per sq. in.*	*Lb. per sq. in.*	*Lb. per sq. in.*	*Pounds*	*Pounds*	*Lb. per sq. in.*	*Lb. per in. of width*	*Lb. per sq. in.*
197	M	9,900	3.7	31	2,370	3,090	456	715	603	1,084	334	765
		17,020	**7.9**	**31**	**5,710**	**7,910**	**1,268**	**1,530**	**974**	**2,116**	**487**	**545**
865		9,030	2.9	35	2,100	3,160	461	850	746	1,154	256	635
				33	**3,780**	**5,840**	**1,209**	**1,437**	**928**	**1,828**	**486**	**1,047**
211	M	6,830	2.6	29	1,930	2,490	456	671	592	1,053	302	564
		15,000	**9.4**	**24**	**5,640**	**6,600**	**1,181**	**1,376**	**746**	**1,714**	**353**	**489**
904	M	8,740	2.3	36	1,790	2,920	496	500		1,146		
		11,310	**5.0**	**27**		**5,200**	**754**	**970**	**699**			
111	M	12,060	4.8	35	3,020	3,780	631	1,006	928	1,373	447	742
197		12,370	5.3	42	3,200	3,870	704	1,035	920	1,380	436	796
		23,270	**11.9**	**40**	**7,620**	**9,790**	**1,893**	**2,110**	**1,584**	**2,784**	**648**	**813**
904	M	13,550	4.7	51	3,430	4,270	917	1,200	1,095	1,612	436	785
				49	**4,420**	**7,340**	**2,018**	**1,776**	**1,532**	**2,354**	**703**	**1,062**
5	M			28		4,020	870	965		1,434		
		17,440	**8.5**	**29**	**5,360**	**7,370**	**1,755**	**1,909**	**1,342**	**2,112**	**603**	
752	M	18,000	8.7	52	4,950	5,880	2,679	1,667	1,766	1,667	428	1,034
		13,900	**4.9**	**22**	**3,850**	**7,040**	**2,842**	**2,150**	**1,796**	**1,451**	**350**	**628**
5	O	12,250	5.6	35		3,080	802	847	1,060	1,292		
		15,470	**7.3**	**30**	**4,650**	**7,120**	**1,246**	**1,598**	**1,208**	**2,118**	**488**	**894**
101		10,840	4.4	43	2,900	3,700	912	1,093	1,057	1,179	424	828
		13,700	**5.8**	**47**	**4,640**	**6,390**	**1,112**	**1,275**	**1,208**	**1,890**	**393**	**773**
211	O	10,020	4.7	44	2,380	3,290	836	1,158	1,108	1,354	428	804
		15,340	**8.6**	**27**	**3,810**	**6,640**	**1,672**	**1,460**	**1,419**	**1,918**	**312**	**653**
294	O	8,320	3.1	28	1,800	2,530	696	807	728	987	334	609
		8,780	**4.0**	**12**	**5,020**	**9,320**	**1,692**	**1,237**	**1,331**	**1,641**	**323**	**808**
319		8,050	3.6	31	1,960	3,070	1,093	1,020	980	1,298	360	784
		9,650	**4.5**	**12**	**4,040**	**7,520**	**2,030**	**1,480**	**1,234**	**1,782**	**412**	**844**
294	O	11,150	3.9	47	3,940	4,690	1,475	1,592	1,570	1,696	525	974
		14,280	**6.7**	**32**	**7,880**	**13,360**	**2,890**	**3,358**	**3,146**	**2,740**	**728**	
226	O	12,010	4.6	35	2,890	3,520	657	971	894	1,212	383	686
		21,200	**9.0**	**42**	**4,830**	**7,840**	**1,178**	**1,336**	**1,209**	**1,600**	**382**	
258	O	10,350	3.4	39	2,650	3,170	707	1,019	996	1,182	384	770
		15,210	**5.9**	**39**	**5,220**	**8,230**	**1,490**	**1,275**	**1,260**	**2,026**	**351**	**792**
751	O	17,200	8.5	57	4,170	5,430	2,517	1,674	1,882	2,210	550	1,041
		21,000	**11.0**	**34**	**5,000**	**8,400**	**3,528**	**3,020**	**2,618**	**2,674**	**518**	**1,012**
319	O	10,260	4.8	49	2,480	3,570	1,375	1,432	1,392	1,634	449	943
		12,720	**5.7**	**23**	**4,880**	**8,570**	**2,558**	**2,090**	**1,783**	**2,210**	**360**	**810**
904	O	11,920	4.2	48		3,680	883	996	1,074	1,293	470	804
		12,280	**3.6**	**45**	**4,770**	**7,030**	**1,289**	**1,642**	**1,536**	**2,126**	**528**	**1,062**
101	O	11,260	4.4	38	2,750	3,330	1,148	1,139	1,074	1,299	420	819
		16,160	**7.3**	**44**	**3,240**	**6,660**	**1,970**	**1,364**	**1,286**	**1,888**	**454**	**820**
258		10,570	3.7	49	2,930	3,620	964	1,172	1,182	1,256	405	756
		19,400	**10.0**	**48**	**4,280**	**7,120**	**1,820**	**1,365**	**1,489**	**1,902**	**416**	**734**
75	O	10,250	3.3	40	2,680	3,460	682	924	892	1,053	388	735
		23,500	**12.7**	**49**	**6,190**	**7,910**	**870**	**1,620**	**1,459**	**1,696**	**554**	
101		10,800	4.2	43	2,550	3,440	844	1,139	1,042	1,220	406	770
		16,800	**7.8**	**36**	**4,490**	**8,150**	**1,386**	**1,605**	**1,448**	**1,945**	**417**	**982**
111		10,580	4.2	36	2,310	3,210	807	1,107	1,011	1,164	425	756
		16,100	**8.1**	**29**	**3,100**	**5,740**	**1,260**	**1,360**	**1,168**	**1,748**	**342**	**674**
226		10,020	3.8	47	1,870	2,700	554	892	854	1,020	388	693
		18,100	**8.0**	**45**	**6,020**	**8,000**	**1,300**	**1,430**	**1,193**	**1,638**	**300**	**690**
534		11,380	4.0	48	2,330	3,730	806	1,021	1,006	1,338	456	740
		18,450	**9.5**	**48**	**5,210**	**6,730**	**1,547**	**1,695**	**1,230**	**1,957**	**374**	**824**
865		10,030	3.2	54	2,450	4,010	829	1,265	1,223	1,448	476	837
		14,040	**5.3**	**53**	**4,460**	**6,970**	**1,426**	**1,820**	**1,404**	**2,119**	**455**	
463	O	8,080	4.3	80	1,330	2,940	1,106	1,213	1,278	1,531	374	749
		14,360	**5.2**	**22**		**5,640**	**2,419**	**2,260**	**1,483**			
904	O	11,880	4.0	54	2,840	4,090	1,030	1,171	1,200	1,411	419	700
		16,400	**6.3**	**53**	**5,740**	**8,640**	**1,401**	**1,734**	**1,417**	**1,964**	**452**	**899**
258	O	9,100	3.1	29	2,220	3,030	675	912	862	934	285	476
		16,520	**8.3**	**26**	**3,040**	**6,800**	**1,175**	**1,048**	**1,100**	**1,532**	**365**	**523**
258	O	12,300	3.8	54	3,820	4,620	944	1,267	1,244	1,321	456	795
		25,200	**13.2**	**49**	**6,910**	**9,720**	**1,730**	**1,640**	**1,538**	**2,183**	**394**	**858**
258	O	10,400	3.2	45	3,000	3,540	707	1,101	1,106	1,262	398	672
		19,240	**8.1**	**41**	**4,500**	**7,580**	**1,420**	**1,310**	**1,257**	**2,187**	**345**	**698**
111	O	13,270	4.8	50	3,580	4,360	943	1,205	1,158	1,296	482	863
		21,720	**10.7**	**49**	**5,550**	**8,030**	**1,408**	**1,609**	**1,556**	**1,998**	**476**	**836**
258	O	11,630	3.8	39	3,260	3,740	766	1,046	1,006	1,240	446	816
		19,440	**8.6**	**44**	**4,040**	**7,200**	**1,315**	**1,452**	**1,215**	**2,014**	**470**	**957**

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Impact bending			Compression parallel to grain		Compression perpendicular to grain; stress at proportional limit	Hardness; load required to embed a 0.444-inch ball to ½ its diameter		Shear parallel to grain; maximum shearing strength	Cleavage; load to cause splitting	Tension perpendicular to grain; maximum tensile strength
Stress at proportional limit	Work to proportional limit	Height of drop causing complete failure (50-pound hammer)	Stress at proportional limit	Maximum crushing strength		End	Side			
21	22	23	24	25	26	27	28	29	30	31
Lb. per sq. in.	*In.-lb. per cu. in.*	*Inches*	*Lb. per sq. in.*	*Lb. per sq. in.*	*Lb. per sq. in.*	*Pounds*	*Pounds*	*Lb. per sq. in.*	*Lb. per in. of width*	*Lb. per sq. in.*
11,750	5.2	35	3,000	3,490	1,004	1,183	1,155	1,253	422	805
17,750	**8.0**	**44**	**5,160**	**7,580**	**1,085**	**1,590**	**1,528**	**2,048**	**488**	**672**
9,860	3.8	40	2,980	3,520	829	1,113	986	1,194	420	686
14,600	**6.4**	**28**	**4,020**	**7,580**	**1,486**	**1,622**	**1,275**	**2,090**	**484**	**818**
10,980	4.3	45	3,130	3,530	727	1,087	1,048	1,306	424	814
17,690	**7.3**	**25**	**5,290**	**8,100**	**1,465**	**1,520**	**1,472**	**2,285**	**444**	**864**
10,390	3.3	46	3,250	3,700	757	1,083	1,039	1,243	416	762
18,760	**8.9**	**53**	**4,710**	**7,180**	**1,310**	**1,412**	**1,190**	**1,950**	**398**	**856**
9,220	2.9	35	2,340	3,000	754	1,022	978	1,184	404	760
17,480	**9.3**	**44**	**4,920**	**8,230**	**1,640**	**1,534**	**1,620**	**1,804**	-------	-------
15,520	8.9	120	3,980	5,810	2,260	1,838	2,037	-------	-------	-------
5,000	2.7	15	1,410	1,750	186	333	281	571	114	224
6,380	**2.9**	**16**	**1,450**	**2,280**	**173**	**298**	**375**	**377**	**72**	**114**
5,400	1.9	7	1,260	1,810	265	349	245	711	149	308
5,510	**1.5**	**7**	**2,550**	**3,510**	**456**	**684**	**388**	**593**	-------	**338**
12,320	5.0	53	3,100	3,990	959	1,274	1,308	1,482	420	677
10,450	**10.4**	**41**	**6,630**	**10,890**	**3,348**	**2,370**	**2,142**	**2,536**	**856**	-------
12,120	4.5	41	3,160	4,170	1,110	1,243	1,279	1,474	410	770
22,420	**11.7**	**35**	**9,350**	**14,050**	**3,908**	**3,730**	**3,178**	**2,666**	**718**	**1,525**
15,970	6.8	40	4,260	4,940	1,500	1,734	1,722	1,510	399	853
-------	-------	-------	**4,690**	**7,310**	**3,210**	-------	**1,997**	-------	-------	-------
8,070	3.3	15	1,220	2,160	900	398	298	908	183	353
-------	-------	-------	-------	**5,530**	**792**	-------	-------	-------	-------	-------
6,180	2.3	18	1,310	1,720	157	261	250	523	140	183
7,750	**2.8**	**14**	**2,970**	**3,750**	**388**	**404**	**316**	**853**	**204**	**325**
5,740	2.2	13	1,130	1,660	178	214	203	486	120	148
8,610	**2.6**	**14**	**3,100**	**4,660**	**384**	**383**	**307**	**800**	**204**	**426**
8,050	2.6	17	2,030	2,550	310	418	338	788	250	464
8,620	**8.9**	**22**	**4,630**	**7,480**	**740**	**590**	**448**	**1,174**	**309**	**572**
9,000	3.8	19	-------	2,310	351	359	341	710	202	442
3,190	**5.4**	**20**	-------	**5,790**	**668**	**629**	**510**	**1,232**	**288**	**529**
-------	-------	26	-------	3,470	886	1,000	864	1,240	-------	-------
9,180	**3.3**	**16**	**5,510**	**9,360**	**1,916**	-------	-------	-------	**322**	**892**
8,470	3.5	37	2,400	2,730	459	609	524	952	303	522
1,680	**6.1**	**31**	**3,720**	**6,060**	**1,469**	**670**	**688**	**1,380**	**302**	**621**
2,230	4.1	63	3,250	4,080	783	1,249	1,244	1,256	402	729
4,460	**12.3**	**58**	**7,740**	**11,020**	**2,301**	**2,487**	**2,028**	**1,720**	-------	-------
9,100	3.3	27	2,140	2,830	428	552	470	931	282	464
6,050	**8.0**	**23**	**4,620**	**6,890**	**860**	**1,057**	**648**	**1,310**	**346**	**484**
0,770	4.1	38	2,700	3,250	678	859	728	1,157	400	713
0,690	**11.5**	**38**	**5,430**	**8,190**	**1,370**	**1,684**	**1,060**	**1,930**	**374**	**446**
-------	-------	54	-------	6,140	2,450	-------	-------	1,816	-------	915
-------	-------	**34**	-------	**9,940**	**2,793**	-------	**2,598**	**1,862**	-------	-------
8,220	3.2	33	1,990	2,800	585	842	739	1,049	377	658
4,140	**7.4**	**37**	**5,930**	**8,450**	**2,008**	**1,642**	**1,108**	**1,450**	**374**	-------
-------	-------	-------	-------	2,680	477	671	590	-------	-------	-------
-------	-------	-------	**5,660**	**7,750**	**1,368**	**965**	**718**	-------	-------	-------
8,180	3.2	24	2,310	2,790	433	664	580	1,001	345	660
1,050	**4.6**	**17**	**3,260**	**5,340**	**885**	**957**	**814**	**1,554**	**420**	**750**
9,420	3.4	29	2,480	3,060	468	729	638	990	319	603
0,560	**3.4**	**39**	**5,280**	**7,220**	**1,142**	**992**	**800**	-------	-------	-------
1,860	4.5	37	3,520	4,300	601	956	899	1,216	358	571
9,450	**11.3**	**33**	**7,780**	**10,660**	**1,965**	**1,110**	**1,083**	**1,476**	**308**	**781**
9,920	4.5	46	-------	3,020	758	-------	-------	-------	-------	-------
1,410	**4.5**	**17**	-------	**8,720**	-------	-------	-------	-------	-------	-------
4,090	1.8	44	860	1,320	193	305	334	562	216	424
5,410	**4.8**	**19**	**2,480**	**4,280**	**633**	**576**	**443**	**1,340**	**271**	**442**
5,170	2.2	27	1,060	1,710	237	391	384	686	248	431
9,940	**4.7**	**12**	**3,220**	**5,780**	**784**	**794**	**548**	**1,342**	**371**	-------
7,640	2.5	33	1,810	2,340	333	488	501	866	210	357
3,960	**7.1**	**30**	**4,490**	**7,120**	**925**	**1,230**	**726**	**1,410**	**350**	**664**
2,440	6.3	40	-------	3,400	619	1,013	977	1,118	-------	-------
-------	-------	-------	**6,410**	**10,000**	**2,172**	**2,555**	**1,946**	-------	-------	-------
9,890	3.3	27	2,800	3,330	468	574	504	879	214	432
2,660	**4.2**	**30**	**6,330**	**7,980**	**955**	**988**	**710**	**1,413**	**226**	**363**
3,640	3.2	27	2,320	2,880	409	517	408	820	142	264
4,580	**7.9**	**29**	**7,030**	**8,080**	**964**	**808**	**581**	**1,117**	-------	**426**

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Sp. gr.	Impact bending			Compression parallel to grain		Compression perpendicular to grain; stress at proportional limit	Hardness; load required to embed a 0.444-inch ball to ½ its diameter		Shear parallel to grain; maximum shearing strength	Cleavage; load to cause splitting	Tension perpendicular to grain; maximum tensile strength
	Stress at proportional limit	Work to proportional limit	Height of drop causing complete failure (50-pound hammer)	Stress at proportional limit	Maximum crushing strength		End	Side			
121	22	23	24	25	26	27	28	29	30	31
	Lb. per sq. in.	*In.-lb. per cu. in.*	*Inches*	*Lb. per sq. in.*	*Lb. per sq. in.*	*Lb. per sq. in.*	*Pounds*	*Pounds*	*Lb. per sq. in.*	*Lb. per in. of width*	*Lb. per sq. in.*
0.32	3,320	2.4	17	2,940	3,270	393	570	389	834	160	284
.48	**5,120**	**5.2**	**17**	**6,290**	**7,200**	**841**	**1,037**	**521**	**905**		**268**
					3,030	518					
.32	3,330	2.7	25	2,980	3,280	385	555	475	881	154	240
.48	**5,600**	**7.2**	**39**	**7,360**	**7,750**	**1,025**	**948**	**696**	**1,496**	**358**	**631**
.30	3,080	3.2	19	2,650	3,040	332	414	354	808	78	142
.46	**5,300**	**4.4**	**23**		**7,240**	**931**	**707**	**528**	**924**	**215**	**390**
.32	3,990	2.7	35	2,540	3,570	864	760	646	1,008	176	331
.48	**6,040**	**4.0**	**25**		**5,210**	**1,046**	**860**			**234**	
.34	3,540	5.4	18	3,910	4,360	911	809	580	1,188	208	398
.48	**5,270**	**4.3**	**17**	**5,080**	**6,370**	**998**	**1,017**	**606**	**758**		
.32	3,360	2.0	16	2,380	2,630	278	394	246	698	132	216
.48	**5,980**	**3.8**	**10**	**5,020**	**6,090**	**554**	**620**	**327**	**848**	**99**	**186**
.32	2,820	2.9	18	2,700	3,050	351	462	272	742	131	195
.48	**5,150**	**3.1**	**21**	**5,720**	**6,540**	**850**	**875**	**428**	**985**	**148**	
.30	3,550	2.5	17	2,330	2,560	376	430	289	691	158	279
.46	**5,320**	**3.6**	**19**	**4,890**	**5,580**	**794**	**796**	**414**	**908**	**152**	**303**
.32	3,290	2.0	15	1,490	1,990	288	321	226	616	144	238
.48	**5,200**	**2.8**	**12**	**2,730**	**4,140**	**389**	**466**	**338**	**902**	**150**	**244**
.30	3,220	1.8	20	1,160	2,220	275	413	306	699	114	150
.46	**5,050**	**2.8**	**14**	**2,600**	**4,370**	**607**	**567**	**372**	**758**	**136**	**230**
.30	3,730	2.5	16	2,160	2,560	326	394	278	690	131	208
.46	**5,810**	**2.9**	**14**	**2,830**	**4,660**	**560**	**488**	**326**	**849**	**130**	**233**
.32	3,290	2.7	23	3,440	3,960	548	460	354	818	160	246
.48	**6,070**	**4.6**	**24**	**5,160**	**7,560**	**715**	**755**	**534**	**994**	**160**	**212**
.30	3,800	2.6	25	2,750	3,170	424	474	403	822	188	310
.46	**5,230**	**4.7**	**27**	**6,000**	**7,770**	**1,034**	**830**	**564**	**1,134**	**178**	**328**
.32	3,340	3.8	26		3,710	509	448	408	782	164	276
.48	**5,740**	**3.8**	**25**		**6,130**	**947**	**648**	**529**	**1,044**	**166**	**304**
.30	3,240	3.5	25		3,510	513	399	370	848	194	380
.46	**5,310**	**3.3**	**22**		**5,770**	**941**	**563**	**448**	**868**	**164**	**214**
.32	3,470	2.8	26	3,780	4,130	558	510	480	906	162	232
.48	**6,520**	**5.8**	**37**	**10,620**	**12,100**	**1,190**	**948**	**858**	**1,340**	**209**	
.32	3,850	3.1	27	3,440	4,080	541	538	514	882	102	161
.48	**5,720**	**6.9**	**42**	**9,290**	**10,940**	**1,356**	**904**	**776**	**1,181**		**206**
.32	3,890	2.7	22	2,780	3,410	485	484	427	940	150	202
.48	**6,090**	**3.2**	**19**	**7,530**	**8,160**	**1,144**	**888**	**776**	**1,253**	**232**	
.32	3,710	4.1	25	3,520	3,830	540	562	524	961	176	294
.48	**6,100**	**6.1**	**41**	**8,270**	**10,200**	**924**	**950**	**805**	**1,385**	**182**	**357**
.32	3,630	3.1	22	3,200	3,770	490	440	449	858	134	172
.48	**5,650**	**4.7**	**25**		**6,990**	**953**	**753**	**642**	**1,064**	**195**	**354**
.32	3,980	3.0	24		4,260	461	481	472	1,144	187	321
.48	**5,700**	**2.8**	**28**		**7,040**	**912**	**787**	**670**	**1,114**	**176**	**354**
.32	4,060	4.5	23		3,470	471	508	440	849	196	334
.48	**6,220**	**6.1**	**26**		**6,550**	**997**	**701**	**569**	**1,162**	**236**	**408**
.32	3,620	3.0	25	2,610	3,450	518	541	483	888	226	320
.48	**5,470**	**5.1**	**32**	**6,630**	**8,250**	**1,088**	**812**	**715**	**1,341**	**200**	**392**
.32	3,810	2.5	19	2,310	3,040	485	513	448	859	224	344
.48	**5,480**	**4.6**	**24**	**6,240**	**7,120**	**1,056**	**740**	**628**	**1,186**	**171**	**394**
.32	3,610	2.7	21	2,790	3,420	447	485	423	781	111	222
.48	**5,720**	**5.4**	**29**	**7,810**	**9,370**	**1,145**	**830**	**614**	**1,164**	**246**	**276**
.32	3,870	2.8	20	2,410	2,920	427	415	408	856	133	
.48	**5,870**	**3.9**	**27**	**4,770**	**6,050**	**744**	**723**	**616**	**1,180**	**122**	
.32	4,260	3.3	20	2,660	3,090	472	482	393	897	195	346
.48	**5,720**	**7.2**	**28**	**5,740**	**8,130**	**1,148**	**782**	**696**	**983**	**198**	**324**
.32	4,280	1.6	9	1,690	2,060	307	284	219	614	132	
.48	**5,660**	**2.1**	**14**	**2,890**	**3,400**	**504**	**421**	**345**	**1,008**	**140**	
.32	3,900	2.3	16	2,080	2,400	210	289	291	612	130	176
.48	**5,460**	**2.9**	**23**	**5,860**	**6,640**	**530**	**744**	**504**	**788**		**180**
.32	10,640	2.0	12	1,630	2,010	194	279	210	595	154	296
.48	**5,290**	**2.7**	**13**	**4,010**	**4,280**	**491**	**502**	**304**	**879**	**172**	**275**
.32	4,900	2.5	25	2,510	3,030	316	448	375	735	146	222
.48	**5,780**	**6.8**	**30**	**5,170**	**6,750**	**614**	**754**	**600**	**1,022**	**310**	**154**
.32	3,270	2.7	19	2,760	3,020	355	387	348	786	154	248
.48	**5,220**	**4.9**	**33**	**5,910**	**7,280**	**1,079**	**882**	**522**	**988**	**119**	**218**
.32	3,890	2.6	20	2,390	2,700	309	305	254	698	126	182
.48	**5,470**	**4.6**	**27**	**6,260**	**7,240**	**846**	**860**	**469**	**1,092**	**155**	**132**
.32	6,430	3.3	18		2,780	374	365	328	806	176	295
.48	**5,140**	**3.6**	**21**		**5,600**	**678**	**753**	**428**	**1,014**	**154**	**336**

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Impact bending			Compression parallel to grain		Compression perpendicular to grain; stress at proportional limit	Hardness; load required to embed a 0.444-inch ball to ½ its diameter		Shear parallel to grain; maximum shearing strength	Cleavage; load to cause splitting	Tension perpendicular to grain; maximum tensile strenght
Stress at proportional limit	Work to proportional limit	Height of drop causing complete failure (50-pound hammer)	Stress at proportional limit	Maximum crushing strength		End	Side			
21	22	23	24	25	26	27	28	29	30	31
lb. per sq. in.	*In.-lb. per cu. in.*	*Inches*	*Lb. per sq. in.*	*Lb. per sq. in.*	*Lb. per sq. in.*	*Pounds*	*Pounds*	*Lb. per sq. in.*	*Lb. per in. of width*	*Lb. per sq. in.*
8,650	2.8	22	-------	2,830	441	387	380	923	191	340
2,090	**4.4**	**23**	**4,830**	**5,870**	**884**	**991**	**514**	**1,080**	**190**	**356**
7,830	2.2	21	2,380	2,670	289	362	310	674	146	238
1,930	**5.3**	**24**	**5,430**	**6,540**	**578**	**716**	**471**	**1,180**	**210**	-------
7,230	2.2	18	2,610	2,800	445	381	328	732	166	258
8,400	**3.2**	**14**	**4,070**	**6,150**	**720**	**775**	**464**	**1,054**	**176**	**258**
7,600	2.9	18	1,810	2,210	290	369	278	734	150	252
0,410	**4.3**	**15**	-------	**5,660**	**778**	**768**	**463**	**1,001**	-------	**226**
0,510	3.3	25	-------	2,920	380	381	366	766	181	326
2,220	**4.5**	**23**	-------	**5,850**	**559**	**780**	**460**	**918**	**146**	**274**
6,330	2.2	17	2,140	2,750	420	463	344	802	160	297
8,220	**3.6**	**13**	**3,570**	**5,740**	**726**	**810**	**392**	**1,148**	**119**	-------
0,490	3.4	24	3,350	3,790	574	558	468	951	160	217
5,710	**8.3**	**35**	**7,370**	**8,380**	**1,400**	**910**	**584**	**1,166**	**102**	-------
7,240	2.4	20	2,540	2,830	382	485	432	800	142	206
1,300	**5.1**	**18**	**3,500**	**5,400**	**918**	**892**	**515**	**842**	-------	-------
8,600	3.4	23	2,350	2,970	396	476	361	838	144	204
0,270	**3.6**	**19**	**3,580**	**5,070**	**752**	**912**	**562**	**1,234**	**200**	**344**
8,770	3.6	36	2,550	2,890	399	579	464	884	200	362
5,600	**7.9**	**36**	**4,460**	**7,510**	**1,419**	**1,289**	**690**	**1,263**	**166**	**336**
0,360	3.4	28	2,530	3,410	545	611	544	936	201	303
2,820	**5.0**	**28**	**5,340**	**7,720**	**1,078**	**1,252**	**852**	**1,285**	**156**	**304**
7,800	2.4	20	2,320	2,890	350	543	432	808	168	256
3,030	**6.0**	**26**	**7,730**	**7,910**	**833**	**1,020**	**621**	**1,172**	-------	**170**
7,700	2.7	21	2,460	2,780	388	449	376	769	191	334
2,160	**5.4**	**23**	**4,890**	**5,810**	**636**	**916**	**527**	**1,178**	**207**	357
8,510	3.0	26	2,640	3,240	458	559	484	840	207	331
3,700	**6.2**	**31**	**6,120**	**7,390**	**806**	**1,073**	**667**	**1,358**	202	341
8,990	3.1	20	-------	3,040	323	507	395	798	168	303
3,150	**5.6**	**24**	-------	**6,270**	**662**	**842**	**502**	**1,094**	**196**	**370**
8,810	3.9	21	2,490	3,730	1,029	963	823	1,281	-------	-------
5,580	**2.4**	**11**	-------	**4,220**	**1,844**	**1,330**	**1,200**	-------	-------	-------
0,380	3.7	24	3,390	3,870	559	466	452	917	158	229
7,000	**8.6**	**34**	**8,170**	**9,640**	**1,280**	**1,385**	**866**	**1,532**	**165**	**336**
-------	-------	-------	3,030	3,700	-------	-------	-------	-------	-------	-------
-------	-------	-------	**4,170**	**5,940**	-------	-------	-------	-------	-------	-------
7,850	3.3	30	2,180	2,580	378	378	366	759	176	308
3,100	**5.6**	**37**	-------	**7,770**	**1,150**	**866**	**736**	-------	**216**	**440**
7,150	2.6	21	2,050	2,370	353	319	342	694	156	258
4,250	**6.2**	**29**	**5,190**	**6,980**	**998**	**742**	**552**	**1,452**	**278**	**410**
7,140	2.6	18	1,850	2,410	315	299	312	737	170	268
3,000	**6.3**	**19**	-------	**7,060**	**917**	**619**	**488**	**826**	**288**	**200**
0,490	3.1	32	2,870	3,670	548	405	452	904	186	284
4,800	**5.9**	**26**	**8,270**	**11,300**	**1,595**	**1,029**	**836**	**1,725**	**236**	**370**
8,580	2.8	29	2,760	3,560	478	434	457	874	173	161
5,700	**4.3**	**33**	**5,550**	**7,690**	**1,018**	**746**	**729**	**1,360**	**316**	**538**
0,120	3.9	31	2,450	3,670	421	439	474	956	154	166
4,120	**5.5**	**31**	**4,980**	**7,500**	**1,029**	**816**	**749**	**1,382**	**276**	**513**
0,510	3.3	34	2,390	3,410	592	436	447	798	222	386
2,310	**4.0**	**34**	**4,340**	**6,840**	**833**	**688**	**675**	**1,246**	**280**	**490**
0,170	2.4	29	2,450	3,410	457	412	440	790	188	326
1,210	**3.5**	**31**	**4,590**	**7,160**	**995**	**741**	**702**	**1,568**	**293**	**548**
7,920	2.3	28	2,310	3,200	424	414	415	750	181	304
0,250	**3.1**	**27**	**4,180**	**6,510**	**877**	**756**	**628**	**1,310**	**238**	**421**
8,410	2.1	16	1,990	2,400	332	316	318	714	226	-------
0,850	**4.4**	**20**	**4,100**	**5,330**	**824**	**493**	**403**	**874**	**134**	-------
6,870	2.3	16	2,200	2,530	364	288	312	710	141	-------
7,600	**2.6**	**15**	**4,530**	**5,320**	**779**	**536**	**484**	**972**	**161**	-------
7,350	2.3	21	2,180	2,770	285	349	347	666	140	229
0,580	**4.6**	**19**	**8,040**	**8,870**	**1,508**	**740**	**654**	**1,046**	**232**	**335**
7,560	2.5	25	1,970	2,670	299	300	323	680	130	198
4,750	**7.5**	**24**	**5,000**	**8,100**	**1,118**	**624**	**548**	**927**	**208**	-------
7,440	2.4	22	2,160	2,600	290	344	350	670	138	224
0,260	**4.5**	**20**	**6,740**	**7,720**	**1,148**	**770**	**616**	**1,056**	**266**	-------
0,680	3.0	35	3,470	4,280	491	574	512	1,006	184	269
5,300	**6.2**	**31**	**6,040**	**8,140**	**1,413**	**924**	**798**	**1,688**	**210**	**374**
0,950	3.4	31	3,540	4,020	513	466	526	1,034	172	274
5,030	**6.2**	**28**	**5,740**	**8,180**	**1,435**	**988**	**850**	**1,426**	**182**	**352**
0,560	3.3	31	3,990	4,550	628	524	595	1,062	174	298
4,890	**5.7**	**29**	**5,680**	**7,990**	**1,492**	**1,010**	**906**	**1,373**	**196**	**355**

Digitized for FRASER

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Sh men no	Impact bending			Compression parallel to grain		Compression perpendicular to grain; stress at proportional limit	Hardness; load required to embed a 0.444-inch ball to ½ its diameter		Shear parallel to grain; maximum shearing strength	Cleavage; load to cause splitting	Tension perpendicular to grain; maximum tensile strength
	Stress at proportional limit	Work to proportional limit	Height of drop causing complete failure (50-pound hammer)	Stress at proportional limit	Maximum crushing strength		End	Side			
1	21	22	23	24	25	26	27	28	29	30	31
	. per . in.	*In.-lb. per cu. in.*	*Inches*	*Lb. per sq. in.*	*Lb. per sq. in.*	*Lb. per sq. in.*	*Pounds*	*Pounds*	*Lb. per sq. in.*	*Lb. per in. of width*	*Lb. per sq. in.*
	150	3.6	33	3,860	4,340	576	542	602	1,066	177	274
31	**,620**	**7.5**	**34**	**9,030**	**12,720**	**1,920**	**1,350**	**1,220**	**1,886**	**246**	**418**
	490	3.8	39	3,880	4,620	707	597	664	1,150	222	324
34	**,310**	**6.5**	**35**	**10,406**	**13,210**	**1,740**	**1,194**	**1,010**	**1,618**	**312**	
	400	3.1	40	3,390	4,710	714	597	641	992	248	428
105	**,510**	**7.0**	**37**	**7,100**	**9,510**	**1,239**	**973**	**992**	**1,766**	**348**	**608**
	100	2.7	34	2,370	3,640	547	562	562	996	254	448
100	**,590**	**5.4**	**35**	**4,770**	**7,350**	**1,148**	**890**	**812**	**1,554**	**336**	**609**
	600	2.4	36	2,780	4,130	531	548	574	955	238	382
100	**,690**	**5.6**	**37**	**4,850**	**7,420**	**887**	**770**	**798**	**1,346**	**334**	**556**
	210	3.8	29	2,980	3,540	559	478	494	956	201	321
22	**,930**	**7.6**	**29**	**4,800**	**8,500**	**1,531**	**832**	**726**	**1,290**	**201**	**378**
	490	2.1	18	2,430	2,720	314	304	296	644	152	255
18	**,280**	**3.3**	**18**	**5,060**	**6,360**	**757**	**611**	**469**	**1,072**	**209**	**339**
	020	3.7	16	--------	2,350	268	296	298	674	154	363
61	**,540**	**5.0**	**18**	--------	**5,450**	**709**	**479**	**411**	**1,034**	**155**	**377**
	810	2.1	16	1,870	2,470	296	303	309	668	141	238
86	**,690**	**3.9**	**20**	**3,650**	**5,280**	**686**	**573**	**416**	**834**	**142**	**268**
	890	1.5	16	--------	2,380	257	318	322	653	132	158
86	**,660**	**4.1**	**18**	--------	**4,860**	**568**	**530**	**390**	**789**	**161**	**339**
	480	2.2	28	2,410	3,080	358	355	342	776	158	192
18	**,090**	**6.3**	**25**	**5,160**	**7,080**	**833**	**696**	**597**	**1,262**	**206**	**468**
	120	3.4	29	2,370	3,040	510	458	484	950	220	354
22	**,150**	**10.7**	**28**	**4,310**	**7,660**	**1,170**	**820**	**690**	**1,566**	**288**	**576**
	820	3.1	26	1,530	2,860	390	378	459	772	154	202
90	**,200**	**4.1**	**35**	**4,770**	**6,460**	**1,255**	**742**	**634**	**1,438**	**270**	**488**
	350	3.2	33	2,940	3,660	544	455	510	936	186	280
31	**,700**	**6.3**	**26**	**9,110**	**10,690**	**1,578**	**1,020**	**889**	**1,716**	**275**	**413**
	910	2.2	20	2,240	2,600	410	315	331	706	153	--------
2	**,020**	**2.7**	**18**	**4,210**	**4,926**	**714**	**618**	**454**	**1,030**	**200**	--------
3	--------	--------	--------	--------	2,770	299	--------	--------	--------	--------	--------
	--------	--------	--------	--------	**6,460**	**701**	--------	--------	--------	--------	--------
	160	2.1	17	1,870	2,220	342	310	314	662	166	301
14	**,100**	**3.1**	**10**	**3,830**	**5,220**	**790**	**546**	**408**	**1,300**	**243**	**403**
	070	2.5	21	2,130	2,420	326	316	314	696	174	241
14	**,050**	**4.6**	**19**	**5,070**	**6,600**	**805**	**563**	**510**	**1,214**	**226**	**446**
	500	2.3	19	2,050	2,370	313	308	322	674	176	302
22	**,800**	**6.0**	**19**	**4,470**	**6,740**	**802**	**567**	**486**	**1,078**	**196**	**381**
	080	3.4	21	--------	2,060	428	258	286	682	168	310
65	**,510**	**5.0**	**19**	--------	**4,780**	**848**	**614**	**473**	**1,433**	**230**	**473**
	790	4.6	25	2,670	3,440	556	465	477	1,143	--------	376
75	**,920**	**5.6**	**18**	**3,950**	**7,080**	**1,145**	**1,130**	**810**	**1,083**	--------	**280**
4	--------	--------	--------	--------	3,570	400	--------	--------	708	--------	--------
	--------	--------	--------	--------	**6,380**	**926**	--------	--------	**1,135**	--------	--------
	210	4.0	39	3,560	4,050	550	494	558	1,071	214	330
34	**,590**	**6.5**	**36**	**7,160**	**10,930**	**1,689**	**944**	**884**	**1,640**	**252**	**406**
	000	2.4	26	1,810	2,860	340	360	364	798	164	246
101	**,340**	**4.3**	**28**	**4,220**	**5,680**	**796**	**594**	**562**	**1,166**	**278**	**451**
	300	2.7	28	2,140	3,480	425	410	457	878	218	360
102	**,950**	**5.0**	**34**	**5,070**	**6,720**	**948**	**802**	**680**	**1,346**	**283**	**522**
	780	2.9	30	2,840	3,480	494	398	414	830	210	356
109	**,040**	**5.7**	**34**	**5,020**	**7,230**	**956**	**744**	**720**	**1,317**	**274**	**464**
	300	3.9	37	3,890	4,470	592	574	628	1,034	190	294
31	**,020**	**7.2**	**42**	**9,100**	**11,890**	**1,622**	**1,205**	**1,159**	**1,924**	--------	**651**
	770	6.7	36	2,880	4,960	820	807	871	1,186	254	511
73	**,610**	**7.8**	**29**	**5,160**	**9,230**	**1,820**	**1,315**	**1,240**	**1,640**	--------	**172**
	800	3.1	33	2,830	4,400	660	559	570	920	244	403
105	**,120**	**4.6**	**37**	**6,090**	**8,060**	**1,177**	**899**	**879**	**1,582**	**296**	**550**
	720	3.2	37	2,910	3,900	675	551	572	958	236	390
100	**,780**	**4.9**	**36**	**5,160**	**8,280**	**1,162**	**1,041**	**917**	**1,686**	**294**	**506**
	740	2.3	17	2,390	2,600	353	334	324	708	178	272
14	**,110**	**4.3**	**17**	**4,490**	**5,190**	**640**	**653**	**463**	**1,082**	**196**	**354**
	240	3.0	18	--------	2,450	349	294	286	640	186	275
55	**,940**	**4.8**	**18**	--------	**4,820**	**570**	**432**	**308**	**1,169**	**186**	**348**
	590	2.3	23	2,820	3,070	303	334	333	712	168	246
22	**,960**	**5.8**	**29**	**5,950**	**7,840**	**810**	**470**	**419**	--------	**123**	--------
	680	2.7	17	--------	2,420	288	293	300	593	153	269
57	**,660**	**4.5**	**21**	--------	**6,170**	**530**	**477**	**376**	**1,000**	**176**	**320**

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Sh men no	Impact bending			Compression parallel to grain		Compression perpendicular to grain; stress at proportional limit	Hardness; load required to embed a 0.444-inch ball to ½ its diameter		Shear parallel to grain; maximum shearing strength	Cleavage; load to cause splitting	Tension perpendicular to grain; maximum tensile strength
	Stress at proportional limit	Work to proportional limit	Height of drop causing complete failure (50-pound hammer)	Stress at proportional limit	Maximum crushing strength		End	Side			
1	21	22	23	24	25	26	27	28	29	30	31
	. per . in.	*In.-lb. per cu. in.*	*Inches*	*Lb. per sq. in.*	*Lb. per sq. in.*	*Lb. per sq. in.*	*Pounds*	*Pounds*	*Lb. per sq. in.*	*Lb. per in. of width*	*Lb. per sq. in.*
46	190	4.2	21	1,810	2,590	475	512	596	918		462
	520	2.8	11		8,080	2,111	1,008	910			
550	310	3.4	22	3,780	4,290	524	569	422	798	157	248
120	690	3.9	19	4,710	6,660	950	862	496	1,018	156	246
126	520	3.0	20	3,630	4,110	523	569	405	809	179	264
	900	3.4	18	4,580	6,060	833	766	469	905	136	222
126	590	2.6	14	2,160	2,740	444	448	304	716	179	288
	420	3.3	13	3,340	4,600	616	690	381	1,018	174	288
126	500	2.2	14	1,640	2,100	248	357	274	604	144	254
	120	2.4	10	2,410	3,580	554	557	322	820	144	220
126	060	2.8	19	3,360	3,780	376	522	384	764	178	271
	570	3.0	19	4,430	5,980	676	767	443	968	156	293
126	740	2.3	17	2,530	2,980	331	436	330	704	178	302
	790	3.4	14	3,370	4,880	662	707	384	930	153	268
86	800	1.8	24	1,540	2,570	175	430	370	662	117	104
	460	6.2	23	5,510	6,070	1,086	762	556	1,096	170	
2	300	2.1	13	1,820	2,170	302	272	264	616	122	
	890	3.5	16	3,550	4,560	589	484	334	1,024	166	
2	350	1.8	15	1,530	1,800	279	231	221	569	136	
	710	2.8	14	2,480	3,060	447	298	244	802	191	
	100	2.3	17		2,700	318	418	368	760	129	212
	330	4.4	23	5,120	5,700	523	638	592	1,214	173	348
22	220	2.3	19	2,340	2,600	368	446	346	764	146	223
	570	5.5	28	5,500	7,310	744	700	515	1,068	184	416
32	940	2.5	29	2,270	2,600	326	433	370	777	148	216
	890	5.2	25	5,100	5,770	1,010	780	532	1,210	165	
50	810	2.7	20	1,920	2,180	222	350	280	696	108	172
	860	3.6	21		4,570	553	693	442	1,206	220	428
56	640	3.5	24		2,840	355	478	350	778	118	162
	850	5.7	28		6,260	796	846	536	1,348	213	415
65	270	3.9	23		2,930	353	478	348	748	164	296
	800	5.0	24		7,470	899	941	499	1,296	210	358
93	350	3.1	23	2,190	2,710	420	395	334	758	150	326
	100	3.8	21	5,170	6,620	714	664	540	1,160	252	346
93	270	2.9	23	2,330	2,810	375	465	396	778	190	298
	250	3.3	30	5,310	6,580	792	1,050	617	1,133	205	439
					2,440	278	394	345	676	126	216
	670	3.5	20	4,070	4,890	455	514	424	1,131	190	350
93	580	2.7	24	2,230	2,720	330	371	352	710	170	231
	070	4.2	22	3,320	6,310	752	649	504	1,239	228	390
30	750	2.0	20	2,140	2,550	267	290	278	691	134	198
18				4,530	7,020	730	984	690	806		
	750	2.7	28	2,930	3,480	480	401	375	863	163	255
16	950	5.7	23	4,980	7,590	1,080	725	636	1,372	228	414
26	110	6.2	38	3,440	4,650	1,040	1,342	1,150	1,621	248	450
	820	5.3	30	5,090	9,220	2,685	2,332	1,795	2,476	190	

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THE USE OF CARBON DISULPHIDE AGAINST THE JAPANESE BEETLE

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UNITED STATES DEPARTMENT OF AGRICULTURE, WASHINGTON, D. C.

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Technical Bulletin No. 478 July 1935

UNITED STATES DEPARTMENT OF AGRICULTURE
WASHINGTON, D. C.

THE USE OF CARBON DISULPHIDE AGAINST THE JAPANESE BEETLE

By W. E. Fleming, *entomologist*, and F. E. Baker, *assistant entomologist, Division of Japanese and Asiatic Beetle Investigations, Bureau of Entomology and Plant Quarantine* [1]

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INTRODUCTION

When the quarantine to restrict the spread of the Japanese beetle (*Popillia japonica* Newman [2]) was first applied several years ago, it was realized that an embargo on the outward movement of nursery products and other agricultural commodities that might carry the insect would work a serious hardship on nurserymen and others within the infested area. The policy was adopted that, provided any infestation present could be removed or destroyed, nursery and farm com-

[1] The writers are indebted to L. B. Smith, formerly in charge, and to C. H. Hadley, now in charge of the Division of Japanese and Asiatic Beetle Investigations, and to other members of the Division for suggestions and criticisms made during the course of this investigation and the preparation of the manuscript.

[2] Information on the life history and habits of this insect is given by Smith and Hadley (*133*).[3]

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modities might be certified for shipment (*132*)[3]. Among the problems presented in the program to reduce the damage by the beetle in the infested area and to prevent its rapid spread, one of the most important was the development of methods for treating soil to destroy the immature stages of the insect without injury to plants.

At the time the experimental work was begun little was known about the treatment of soil with chemicals to destroy the insect. Many insecticides were tried with various degrees of success, but it was early demonstrated that carbon disulphide, an organic chemical the insecticidal property of which appears to have been first recognized in 1854 by Garreau (*41*), was one of the most effective and practical chemicals for fumigating soil.

Experiments with carbon disulphide have been carried on by the writers and other investigators[4] at the laboratory during the period 1920 to 1931, inclusive, to determine the effectiveness of this chemical in destroying the immature stages of the insect under different conditions. In the course of this investigation, 750,000 individuals of the different stages of the insect, 170,000 plants, and several acres of fallow land and turf were treated. It was possible to complete some phases of this problem in a few months, but it was necessary to continue the experimentation with the more complex phases for several years. As several hundred individuals were used in every test except the preliminary tests, it is believed that a sufficient number of insects and plants were used in all cases.

The results of some phases of this investigation have been published in different technical journals, and some of the methods that have been developed have been in commercial use for several years. In view of the general interest in carbon disulphide for the control of soil-infesting insects, the writers have attempted to bring together a summary of the published and unpublished experimental data and the pertinent facts relating to the use of this chemical against the Japanese beetle.

USE OF CARBON DISULPHIDE AGAINST OTHER SOIL-INFESTING INSECTS

The injection of carbon disulphide to destroy the grape phylloxera (*Phylloxera vitifoliae* Fitch) on the roots of grapevines was the beginning of the use of this material to control soil-infesting insects. In 1869 Thenard, as reported by Bourcart (*8*), Gastine, Couanan, and Gastine (*42*), and Henry (*60*) recommended the injection of carbon disulphide into the soil as a means of controlling this insect, which was threatening to destroy the grape-growing industry of France. Research by Monestier, Lautaud, and Ortoman in 1873, and by Crolas in 1877, as reported by Bourcart (*8*), by Marion (*96*, *97*, *98*) in 1878, 1879, and 1880, by Gastine, Couanan, and Gastine (*42*) in 1884, by Battanchon (*4*) in 1894, by Vermorel (*153*) in 1901, by Börner and Thiem (*7*) in 1925, and by Faes and Tonduz (*21*, *23*, *pp. 347–355*) in 1926 and 1927 has established the efficacy of the treatment against the phylloxera.

In 1880 Cook (*14*) injected carbon disulphide into the soil to control the cabbage maggot (*Hylemyia brassicae* Bouché). The use of

[3] Italic numbers in parentheses refer to Literature Cited, p. 82.
[4] J. W. Lipp, M. R. Osburn, B. R. Leach, J. P. Johnson, J. W. Thomson, and R. Wagner.

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the material for this purpose was further investigated by Slingerland (*129*) and Smith and Dickerson (*131*). Under favorable conditions the maggots were destroyed without causing serious injury to the plants. The effectiveness of the treatment varied with the condition of the soil and failed to gain general approval.

In 1881 Danvesse and Duplessis, as reported by Vermorel (*153*), pointed out theeffectiveness of injections of this chemical in killing the larvae of the cockchafer (*Melolontha vulgaris* L.) in nursery seedling beds. The use of carbon disulphide for this purpose was further investigated by Falconnet and Treyre, as reported by Bourcart (*8*), and by Vermorel (*153*), Rolet (*118*), Faes and Staehelin (*22*), and Köbelin (*75*) with the general conclusion that injection of carbon disulphide reduced the injury by this insect to negligible proportions.

Comstock and Slingerland (*13*), Frank (*34*), and Melander (*104*) reported favorable results in the control of wireworms, the larvae of Elateridae, by the injection of carbon disulphide. Marre (*99*) and investigators in England (*49*) concluded that its effect was too dependent upon favorable soil conditions to be recommended generally for the control of wireworms.

In 1896 Stedman (*136*) tried injections of carbon disulphide against the woolly apple aphid (*Eriosoma lanigerum* Hausm.), and Gillette and List (*44*), in 1915, mentioned it as a control measure. Leach (*79*), in 1920, found that the treatment did not destroy all the aphids, and that those surviving served as a source of reinfestation. All these investigators found that it was impossible to apply the treatment at any season of the year when the soil conditions were favorable without causing injury to the trees.

In 1902 Woodworth (*165*) recommended injection of carbon disulphide for the control of the western peach borer (*Aegeria opalescens* Hy. Edw.). Becker (*5*) and Blakeslee (*6*), who later tried this chemical against the peach borer (*A. exitiosa* Say), found that it was effective as a larvicide, but they did not recommend the treatment for general use because of the variable action of the chemical under different conditions.

It was reported by Headlee and Dean (*56*), in 1908, and later by J. B. Smith (*130*), that injections of carbon disulphide were successful in destroying ants in the soil.

Headlee, in 1916 (*54*), and Komp, in 1920 (*76*), reported having obtained control of white grubs (*Phyllophaga* spp.) in grasslands by injecting carbon disulphide. Jarvis (*67, 68, 69, 70*), who was successful in controlling the larvae of the cane beetle (*Lepidoderma albohirtum* Waterh.) by this method, recommended its use, although in some cases disappointing results had been obtained by growers who treated ground when it was not in a suitable condition, or who did not have satisfactory mechanical appliances for distributing the chemical. Otanes (*111*) was successful in destroying the root grub (*Leucopholis irrorata* Chevr.), and McKinney and Milam (*95*) obtained favorable results against the larvae of the green June beetle (*Cotinis nitida* L.) by injecting carbon disulphide into soil. Gardner (*40*) reported the destruction of a mealybug (*Pseudococcus* sp.) in the soil of potted plants by this procedure.

Carbon disulphide has been applied as a fumigant to crops after their removal from soil in the same manner as it is generally used for treating grain and other stored products (*64*). In 1913 Chittenden

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(*11*) destroyed infestations of the potato tuber worm (*Gnorimoschema operculella* Zell.) by fumigating with carbon disulphide. Graf (*47*), in 1917, and Spencer and Strong (*134*), in 1925, published further information on the use of carbon disulphide against the tuber worm. Mackie (*94*), in 1923, reported that fumigation with carbon disulphide in a closed chamber was successful in destroying the pear root aphid (*Eriosoma lanuginosum* Hart.) on pear stock.

With the object of overcoming the harmful effect of carbon disulphide on grapevines under certain conditions, Cauvy, as reported by Bourcart (*8*), in 1875, proposed mixing carbon disulphide with water before applying the chemical to the ground. Leach (*78*), in 1918, and Townsend (*147*), in 1920, reported that the woolly apple aphid (*Eriosoma lanigerum*) could be destroyed by this method without appreciable injury to the trees. Blakeslee (*6*), in 1919, obtained better results with carbon disulphide-water mixtures against the peach borer (*Aegeria exitiosa*) than with the chemical alone. This procedure has not come into use in the commercial orchards, chiefly because of the large quantity of water required and the difficulty of applying the treatment on sloping ground.

In more recent years it has been recognized that carbon disulphide may be more readily dispersed in water and the concentration more accurately controlled by emulsifying the compound. In 1914 Bordaz (*1*) successfully used a dilute emulsion of carbon disulphide to control grubs of *Exophthalmus famelicus* Oliv. in the soil about the roots of cacao and coffee plants. Headlee (*58, Rept. 45, pp. 306–317; Rept. 46*) reported that emulsified carbon disulphide was effective in destroying wireworms in lettuce frames and in beet and cabbage fields. Zappe and Garman (*166*) and Johnson (*72, 73*) found an emulsion of this chemical to be the most promising fumigant for controlling the Oriental beetle (*Anomala orientalis* Waterh.) in grasslands. Lipp (*91*) observed that the treatment of grasslands with carbon disulphide emulsion controlled the larvae of the green June beetle (*Cotinis nitida*). Headlee and Ilg (*57*) obtained control of the raspberry root borer (*Bembecia marginata* Harr.), and Herrick (*61*) reported destruction of the symphylid *Scutigerella immaculata* Newp. by application of this emulsion to the soil. Not very favorable results with carbon disulphide emulsion were reported by Dozier (*19*) with larvae of *Phyllophaga portoricensis* Smyth, by Thomas (*142*) with the changa (*Scapteriscus vicinus* Scudd.), and by Britton (*9*) with wireworms. This chemical has been found, however, to be one of the most effective fumigants for destroying soil-infesting insects.

CARBON DISULPHIDE AND ITS EMULSIONS

CHEMICAL PROPERTIES OF CARBON DISULPHIDE

Pure carbon disulphide is a colorless, readily volatile liquid with a pleasant ethereal odor and a rather sharp taste. The commercial grade, which is usually employed for insecticidal work, has a yellowish color and often a disagreeable fetid odor because of the presence of sulphites, sulphates, and foreign sulphides, which form readily on standing, especially in the presence of moisture and light.

Chemically, carbon disulphide is analogous to carbon dioxide. As carbon dioxide forms carbonates with oxides of the alkalies, so carbon

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disulphide forms analogous compounds, namely, the thiocarbonates, with sulphides of the alkalies.

The physical properties of carbon disulphide (CS_2) may be summarized briefly as follows:

Calculated molecular weight	76.13 (*65*).
Specific gravity of liquid, referred to water at 4° C	at 0° C., 1.29215 (*144, p. 364*). at 9.7° C., 1.2773 (*90*). at 15° C., 1.27055 (*146*). at 20° C., 1.2634 (*146*). at 22° C., 1.256 (*65*). at 30° C., 1.24817 (*146*). at 46.25° C., 1.22093 (*151*).
Freezing point	−111.8° C. (−169.2° F.) (*145*).
Heat of fusion	660 calories per gram (*105*).
Boiling point (at normal atmospheric pressure).	46.25° C. (115.2° F.) (*146, 151*)
Coefficient of viscosity, liquid (C. G. S.)	at −10° C., 4950×10^{-6} (*65*). at 0° C., 4290. at +20° C., 3670. at +40° C., 3190.
Coefficient of viscosity, vapor (C. G. S.)	at 16.9° C., 92.4×10^{-6} (*65*).
Heat of vaporization	84.07 calories per gram (*103*).
Coefficient of compressibility of liquid per atmosphere ranging from 1 to 500.	66×10^{-6} (*65*).
Surface tension of liquid in contact with air at 20° C.	31.7 dynes per cm (*65*).
Vapor pressure	at 0° C., 127.9 mm (*65*). at 10° C., 198.5. at 20° C., 298.0. at 30° C., 434.6 at 40° C., 617.5. at 50° C., 857.1.
Theoretical weight of vapor in an atmosphere saturated with vapor expressed in pounds per 1,000 cubic feet	at 0° C., 35.5 (*116*). at 15° C., 65.0. at 20° C., 77.3. at 25° C., 91.2. at 30° C., 108.7. at 35° C., 128.2. at 40° C., 150.0. at 45° C., 174.5. at 50° C., 179.4.

Carbon disulphide is a good solvent for fats, oils, iodine, and resins. It is itself soluble in all proportions in alcohol and ether (*65*), but it is only sparingly soluble in water. One liter of water at 22° C. can absorb 1.74 cc of carbon disulphide, but 1 liter of carbon disulphide can absorb 9.61 cc of water (*125*). The quantity of carbon disulphide that dissolves in water is appreciably influenced by temperature. At a pressure of 1 atmosphere 1 liter of water can dissolve the following quantities of carbon disulphide (*125*):

	Grams		*Grams*
At 0° C	2.04	At 30° C	1.55
At 5° C	1.99	At 35° C	1.37
At 10° C	1.94	At 40° C	1.11
At 15° C	1.87	At 45° C	.70
At 20° C	1.79	At 49° C	.14
At 25° C	1.69		

Carbon disulphide should be handled carefully because of its inflammability and explosiveness. It ignites spontaneously in air at a temperature of 149° C. (300.2° F.) (*102*), burning with a faint blue flame, scarcely visible in daylight, evolving considerable heat and decomposing the compound into carbon dioxide and sulphur dioxide.

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The autoignition temperature is appreciably influenced by the presence of certain metals and glass. The compound has been found to ignite spontaneously in the presence of platinum at about 149° C. (300° F.) (*101*), at 135° C. (275° F.) on copper (*143*), at 132.8° C. (271° F.) on chromium (*143*), at 133.3° C. (272° F.) on low-carbon steel (*143*), and at 127° C. (260° F.) on pyrex glass (*143*). It has been reported to have ignited spontaneously when dropped into a copper vessel containing water at a temperature of 100° C. (212° F.) (*38*). The lowest temperature reported for the ignition of the chemical in contact with copper is 96° C. (204.8° F.) (*159*).

In the open, carbon disulphide is readily ignited by a spark or a flame, even when the temperature of the vapor is —20° C. (—4° F.) (*2*), but in an enclosed chamber the ignition depends upon the supply of oxygen. Carbon oxysulphide (*161*) lowers the limit of flame propagation and facilitates the burning of carbon disulphide. The burning of carbon disulphide is apparently accelerated by this product of its combustion, but is apparently inhibited by the presence of other combustibles such as pentane, ethyl ether, acetylene, or methane (*162*). The fire hazard is reduced by mixing carbon disulphide with carbon tetrachloride (*46*).

Liquid carbon disulphide is not explosive, but the heavy vapor, when mixed with three times its volume of oxygen, or with air containing this quantity of oxygen, is highly explosive in the presence of a flame or at a temperature of 149° C. (300° F.) (*64*). The velocity of the propagation of the explosion has been calculated to be 1,960 meters (6,430 feet) per second and has been actually observed to be 1,802 meters (5,913 feet) per second (*89*). The hazard of explosion may be reduced by mixing the chemical with several times its volume of carbon tetrachloride (*106*) or with carbon dioxide (*46*), but these mixtures are still dangerous. It has been found that a mixture of carbon disulphide and carbon tetrachloride containing only 5 percent of carbon disulphide would flash at a temperature of 20° C. (68° F.), although it would not continue to burn.

DETECTION AND ESTIMATION OF CARBON DISULPHIDE

A search of the literature has shown that there are several methods which might be used for the detection and quantitative estimation of carbon disulphide. The most satisfactory of these procedures appeared to be those in which the compound is absorbed in an alcoholic solution of potassium hydroxide and the amount of carbon disulphide determined colorimetrically, gravimetrically, or volumetrically. As there was not sufficient information in regard to the value and trustworthiness of these procedures, each was carefully tested before selecting the one to be used in the experimental work at the Japanese beetle laboratory.

In the colorimetric procedures, used with considerable variation by a number of investigators (*18, 42, 59, 96, 117*), the carbon disulphide is absorbed in alcoholic sodium hydroxide or potassium hydroxide. The excess alkali is neutralized with acetic acid, and a measured volume of a standard copper solution sufficient to precipitate all of the sulphur is added. The resulting color is compared with standard solutions containing the same quantities of the reagents and known quantities of carbon disulphide.

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In the gravimetric methods, which also vary as to details (*71*, *93*, *126*, *135*), the carbon disulphide is absorbed in alcoholic sodium hydroxide or potassium hydroxide, the solution is neutralized with acetic acid, and copper sulphate solution is added until the supernatant liquid is of a greenish-blue color. The carbon disulphide in the solution is precipitated as copper xanthate. The copper xanthate is collected on an ashless filter, washed, and burned to copper oxide in a porcelain crucible. The quantity of carbon disulphide is calculated from the weight of copper oxide obtained. Instead of adding the copper solution, the alkaline xanthate can be oxidized to sulphuric acid by means of potassium permanganate (*124*), hydrogen peroxide (*25*), or bromine (*135*, *158*, *160*). After the oxidation is completed, the solution is made slightly acid with hydrochloric acid, filtered, and treated with barium chloride solution. The resulting precipitate of barium sulphate is collected on an ashless filter, washed, dried, and weighed.

In one of the volumetric procedures the alkaline xanthate solution is neutralized with acetic acid and titrated with a standard solution of copper (*53*, *93*, *126*, *135*) until a slight excess of copper is in the solution. Potassium ferrocyanide, which turns reddish brown in the presence of copper in solution, is generally used as an internal or as an external indicator to determine the end point of this reaction, but recently an alcoholic solution of guaiac resin (*126*) has been recommended for this purpose. The quantity of carbon disulphide is determined from the quantity of the standard copper solution required to convert the alkali xanthate into copper xanthate.

In another volumetric procedure the alkaline xanthate is neutralized with acetic acid, and a known volume of standard copper solution in excess of the quantity required to precipitate all of the sulphur is added (*66*, *100*). The precipitate of copper xanthate is removed and the determination made by one of several methods. By one of these the filtrate is treated with hydrochloric acid, evaporated almost to dryness, and neutralized with ammonium hydroxide. Solid potassium iodide is added. The solution is then titrated against a standard sodium thiosulphate solution to determine the quantity of iodine liberated by the copper salt. The quantity of excess copper is deducted from the quantity added to the xanthate solution to determine the quantity that reacted with the alkali xanthate.

In the third volumetric method (*17*, *42*, *114*) the alkaline xanthate is neutralized with acetic acid, a small quantity of sodium bicarbonate and starch is added, and the solution is titrated directly with standard iodine solution.

After making several tests with these different procedures, it was found that the direct iodometric titration gave practically perfect checks in duplicate analyses of the same sample, the average recovery being about 99 percent. It had the advantage of being a fairly rapid procedure and was found to be the most convenient in connection with the insecticide work.

The following reagents are required in the iodometric determination of carbon disulphide:

(1) An iodine solution (N/10) prepared according to the procedure outlined by the Association of Official Agricultural Chemists (*3*).
(2) Acetic acid (50 percent).
(3) Sodium bicarbonate of the chemically pure grade.

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(4) Alcoholic potassium hydroxide, prepared by saturating 95-percent ethyl alcohol with potassium hydroxide and filtering.
(5) Phenolphthalein indicator.
(6) Starch indicator, prepared by mixing 0.5 g of starch with 100 cc of cold distilled water, boiling and filtering.

In order to determine the quantity of carbon disulphide in soil, or water, by the iodometric method, it is necessary to vaporize the compound and to absorb the vapors in alcoholic potassium hydroxide for estimation. One of the most satisfactory procedures for accomplishing this is to place the material containing carbon disulphide in a large pyrex test tube, or similar container, raise the temperature to 90° C., and wash the carbon disulphide into the alcoholic potash by passing a warm stream of carbon dioxide-free air through the system. Mohr potash bulbs were found to be satisfactory absorbers for removing the carbon disulphide from the air. When air containing carbon disulphide vapor was to be analyzed, the samples were taken in partially exhausted balloon flasks containing alcoholic potash.

Carbon disulphide reacts with alcoholic potash to form potassium ethyl xanthate, a yellow crystalline addition compound that is very soluble in water. The reaction is indicated by the following equation:

$$C_2H_5OH+KOH+CS_2=C_2H_5OCS_2K+H_2O$$

The solution is diluted with distilled water and neutralized with acetic acid, using phenolphthalein as an indicator and taking care to avoid excess acidity. Solid sodium bicarbonate is added. The standard iodine solution is added slowly from a burette until a faint blue color appears with a few drops of starch solution. The iodine converts the acidified xanthate into a complex sulphur compound according to the following reaction:

$$2C_2H_5OCS_2H+I_2=(C_2H_5OCS)_2S_2+2HI$$

As each cubic centimeter of the standard iodine solution is equivalent to 7.61 mg of carbon disulphide, the quantity (in milligrams) of carbon disulphide can be readily calculated by multiplying the number of cubic centimeters required by 7.61.

PREPARATION OF CARBON DISULPHIDE EMULSIONS

When carbon disulphide is mixed with water—a liquid in which it is almost insoluble and from which it differs considerably in density—the mixture has a marked tendency to separate into two distinct layers. If there is a small quantity of carbon disulphide in a relatively large volume of water, it is possible to disperse the chemical mechanically in small drops of different sizes by agitation. The mechanical mixture is extremely unstable owing to the high interfacial tension between the liquid phases, and separates into two layers if allowed to stand. Such mechanical mixtures of carbon disulphide and water have been used as insecticides (*78*), but because of the difficulty in controlling the concentration and obtaining a uniform mixture, they have not been entirely satisfactory. Special equipment has been developed by French investigators (*8*) for saturating water with carbon disulphide, but it can be depended upon to produce a definite concentration of carbon disulphide only when a constant temperature is maintained.

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Carbon disulphide can be dispersed most easily as small globules in water by adding an emulsifying agent which lowers the interfacial tension between the two liquids. Soap is one of the most generally used emulsifiers, and it has found a wide use in industrial processes for emulsifying fats and oils. Extensive investigations on soap as an emulsifier have been carried on by Pickering (*112*), White and Marden (*163*), Shorter and Ellingworth (128), Hillyer (*62*), Lenher and Bishop (*88*), Griffin (51), Van der Meulen and Rieman (*152*), and others. A creamlike stock emulsion can be made by agitating a mixture of soap, water, and carbon disulphide; or a clear liquid, resembling a miscible oil, may be produced by dissolving the soap in an alcohol or cresol before mixing it with carbon disulphide. These concentrated mixtures of carbon disulphide and emulsifier can be diluted with water until the desired concentration is obtained.

STOCK CARBON DISULPHIDE EMULSIONS

Several stock emulsions have been prepared during the experimentation with emulsified carbon disulphide against the different stages of the Japanese beetle. The formulas of the best of the stock emulsions used at the laboratory are as follows:

FORMULA 1 (*86*)

	Parts by volume
Carbon disulphide	1
Castor oil	1
Turpentine	1
Soap solution	4

½ pound of hard soap dissolved in 1 gallon of water.

FORMULA 2 (*80; 83; 85; 133, p. 49*)

Carbon disulphide	10
Rosin-fish oil soap (cold-water soluble)	1
Water	3

FORMULA 3 (*84*)

Carbon disulphide	5
Rosin-fish oil soap solution	2

125 grams of "old style" rosin-fish oil soap dissolved in 875 cc of water.

FORMULA 4 (*91*)

Carbon disulphide	472
Oleic acid (U. S. P. grade)	16
N/5 sodium hydroxide solution	173

FORMULA 5 (*91*)

Carbon disulphide	7
Soap solution	3

Lump rosin, 50 pounds.
Sodium hydroxide, 9.5 pounds.
Oleic acid (U. S. P. grade), 6 gallons.
Water, 70 gallons.

The commercial soaps used in formulas 2 and 3 were not satisfactory, because it was found that the emulsifying power of these soaps was uncertain, owing to the variation in the composition of the constituents of different batches of the same soap. It was necessary, therefore, to determine the emulsifying power of each batch of commercial soap and modify the formulas accordingly before satisfactory

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stock emulsions could be prepared. Furthermore, the stock emulsions prepared with the commercial soaps were stable for only a few days, emulsified carbon disulphide tending to settle to the bottom of the container, leaving a layer of the soap solution at the top. It was necessary to agitate these emulsions thoroughly before using them in order to assure homogeneity. On long standing, or upon exposure to a temperature below 40° F., the films of soap around the globules of carbon disulphide tended to rupture, causing the globules to coalesce, and the emulsion to separate into three distinct layers—soap solution, emulsified carbon disulphide, and unemulsified carbon disulphide. When the emulsion separated in this manner, it was practically impossible to restore it to homogeneity by agitation.

In view of the difficulties with the commercial soaps as emulsifiers, Lipp (*85*, *91*) developed the sodium oleate-rosin soap emulsifier (formula 5), which is easily prepared and fairly constant in emulsifying power. The emulsion prepared with this soap as an emulsifier remains relatively stable for several months, provided it is not exposed to a low temperature. Carbon disulphide can be readily emulsified with sodium oleate-rosin soap when the ingredients are warm, but when they are cool emulsification is a slow process. This stock emulsion is a rather viscous material and somewhat difficult to measure in small quantities, but this difficulty can be largely overcome by increasing the volume of water before attempting to measure a small quantity of the emulsion. It was the practice when this emulsion was used in the commercial nurseries for the treatment of individual plants to dilute it with an equal volume of water. When diluted in this manner the stock emulsion must be agitated each time before it is used, in order to assure the homogeneity of the emulsion.

The rate at which this diluted stock emulsion stratified on standing was studied in the laboratory. Five hundred cubic centimeters of the stock emulsion was diluted with an equal volume of water, thoroughly mixed, and placed in a glass cylinder 4.8 cm in diameter and 65 cm in height. At intervals, samples of the liquid were taken from the bottom and at a point 10 cm below the surface and analyzed to determine the concentration of carbon disulphide. The results obtained are shown in table 1.

TABLE 1.—*Rate of stratification of carbon disulphide emulsion made with sodium oleate-rosin soap but diluted with an equal volume of water*

Time of sampling (minutes)	Concentration of carbon disulphide	
	10 cm below surface	At the bottom
	Percent [1]	*Percent* [1]
0	35.0	35.0
15	30.8	35.0
45	29.0	40.7
240	16.2	50.3

[1] By volume.

It is readily apparent that on standing undisturbed this stock emulsion stratified rapidly after being diluted with an equal volume of water.

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Agitation causes this diluted stock emulsion to foam, thus making the meniscus difficult to read in a graduated glass cylinder and tending to cause a loss of carbon disulphide. An analysis of the diluted stock emulsion after it had been used in a commercial nursery by an inspector for 2 hours showed that the concentration of carbon disulphide had decreased from 35 to 31.1 percent by volume.

It was apparent that the physical properties of the stock emulsion containing sodium oleate-rosin soap as an emulsifier made it somewhat unsatisfactory where it was necessary to measure it in small volumes, as was the case when individual trees were treated in the nurseries. When it was not necessary to measure small quantities of the emulsion, as in the treatment of grasslands, which called for a large volume of water (500 to 600 gallons), the stock emulsion containing sodium oleate-rosin soap proved to be entirely satisfactory.

MISCIBLE CARBON DISULPHIDES

Attention was directed to the development of a miscible carbon disulphide that would be stable under a wider range of environmental conditions than the stock emulsions and that could be measured more accurately in small volumes. Many alcoholic and phenolic solutions of soaps were prepared and mixed with carbon disulphide. It was found that a certain quantity of alcohol or phenol was necessary to keep the soap in solution when mixed with carbon disulphide, but it was also found that increasing the alcohol beyond a certain proportion tended to prevent the proper dispersion of the chemical when the mixture was added to water. In the case of the vegetable oils, it was necessary to keep the quantity of alkali considerably below that theoretically required to saponify the oils completely, in order to avoid the presence of free alkali and the consequent conversion of the carbon disulphide in the presence of alcohol into the less toxic xanthate. It was desirable to balance the proportions of the ingredients in such a manner that the stock solutions would not separate into two layers when cooled to 32° F., that the carbon disulphide would disperse readily in water, and that the formation of xanthate would be inhibited. Several miscible carbon disulphides have been prepared which satisfy, to some extent, these requirements.

The mixture prepared according to formula 6, which follows, is a clear, dark colored liquid, that, when freshly prepared, mixes readily with water in all proportions:

FORMULA 6

Carbon disulphide	cubic centimeters	825
Oleic acid, U. S. P	grams	60
Beta naphthol	do	65
Sodium hydroxide solution (37.5 percent)	cubic centimeters	78
Rosin	grams	160

In preparing this mixture, the oleic acid, beta naphthol, and rosin are dissolved in the carbon disulphide, and then the alkaline solution is added gradually with constant agitation. On standing, however, a black sediment gradually settles out of the solution, and a foreign sulphurous odor develops. When this occurs, it is difficult to disperse the carbon disulphide properly in water.

Certain alcoholic solutions of potassium oleate, when mixed with carbon disulphide according to formulas 7 or 8, form amber colored, translucent liquids that have been found to remain stable for several months under normal conditions, although there is some tendency for

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some of the emulsifier to crystallize and for some of the carbon disulphide to be converted to the xanthate. These mixtures are made up according to the following formulas:

FORMULA 7 (*29*)

		Parts by volume
Carbon disulphide		7
Alcoholic soap solution		3
Oleic acid, U. S. P.	cubic centimeters	86
Potassium hydroxide	grams	15
Denatured alcohol	cubic centimeters	214

FORMULA 8 (*28*, *29*)

Carbon disulphide		7
Alcoholic soap solution		3
Oleic acid, U. S. P.	cubic centimeters	77
Cottonseed oil	do	30
Denatured alcohol	do	193
Potassium hydroxide	grams	13. 5

These mixtures were prepared by dissolving the emulsifier in the alcohol and then adding the carbon disulphide. Considerable care had to be exercised in diluting these mixtures with water in order to form a satisfactory diluted emulsion. When poured directly into water, only a portion of the carbon disulphide dispersed in the water, and the remainder collected on the bottom of the container. It was found that if a small volume of water was added to the miscible carbon disulphide and agitated, the mixture would form a satisfactory emulsion when poured into a large volume of water.

The mixtures of carbon disulphide with alcoholic solutions of partially saponified vegetable oils are similar in appearance to the mixture of carbon disulphide and an alcoholic solution of potassium oleate, but they disperse more readily in water. The mixtures containing cottonseed oil, coconut oil, peanut oil, and corn oil proved to be unsatisfactory because of the appearance of a sediment and the formation of xanthate on standing for several weeks. The formulas of the best of these mixtures containing the different oils are as follows:

FORMULA 9 (*33*)

		Parts by volume
Carbon disulphide		35
Alcoholic soap solution		65
Blown castor oil	grams	832
Potassium hydroxide	do	37
Denatured alcohol	do	86
Water	do	45

FORMULA 10

Carbon disulphide	1
Alcoholic soap solution	1

Soap solution the same as formula 9.

FORMULA 11

Carbon disulphide		7
Cresylic soap solution		3
Blown castor oil	grams	280
Cresylic acid, 97 percent	cubic centimeters	200
50 percent potassium hydroxide solution	do	82

FORMULA 12

			Parts by volume
Carbon disulphide			7
Alcoholic soap solution			3
Cottonseed oil	cubic centimeters	200	
Potassium hydroxide	grams	10.2	
Alcohol	cubic centimeters	70	
Water	do	30	

FORMULA 13

Carbon disulphide			7
Alcoholic soap solution			3
Coconut oil	cubic centimeters	120	
Potassium hydroxide	grams	23.8	
Alcohol	cubic centimeters	126	
Water	do	54	

FORMULA 14

Carbon disulphide			7
Alcoholic soap solution			3
Peanut oil	cubic centimeters	200	
Potassium hydroxide	grams	10.2	
Alcohol	cubic centimeters	82	
Water	do	18	

FORMULA 15

Carbon disulphide			7
Alcoholic soap solution			3
Corn oil	cubic centimeters	200	
Potassium hydroxide	grams	10.2	
Alcohol	cubic centimeters	82	
Water	do	18	

FORMULA 16

Carbon disulphide	7
Alcoholic soap solution	3

Soap solution the same as in formula 9.

The best of these mixtures are those containing castor-oil soap and alcohol. The substitution of cresylic acid for alcohol, as in formula 11, tended to hasten the formation of sediment and, on standing, produced a foreign sulphurous odor. The mixture of 7 parts of carbon disulphide with 3 parts by volume of the alcoholic solution of castor-oil soap (formula 16) formed a stock solution that separated into 2 layers when cooled to 40° F. It became homogeneous again, however, when warmed to 70° and reagitated. The solutions containing castor oil, which were prepared according to formulas 9 and 10, have been held for 1 week at a temperature of 32° without separating into 2 layers.

The mixture containing an equal volume of castor-oil soap solution and carbon disulphide (formula 10) appeared to have the most satisfactory physical properties for use in the commercial nurseries. It is a mobile, translucent liquid with a specific gravity of 1.555 at 15°/4° C. It does not form a heavy foam when shaken, and it can be poured easily and measured accurately in small quantities. It has remained homogeneous for several months under normal conditions. It mixes easily with water in all proportions, forming a milky emulsion. In view of the use of this emulsion at the present time for the treatment of nursery stock, the description of its ingredients and preparation is given in greater detail.

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The castor oil used in formula 10 should have a specific gravity between 0.991 and 1.004 at 15°/4° C., an iodine number between 60 and 53, a saponification number between 205 and 216, and a titer of 3. The fatty acids in this oil should have an iodine number between 63 and 53 and an acid value between 210 and 225. Ethyl alcohol that has been denatured according to formula 1 of the Bureau of Internal Revenue, United States Treasury Department, containing 10 parts by volume of methanol and 0.5 part of benzene to 100 parts of ethyl alcohol, is satisfactory. The alcohol should be 190 proof. The potassium hydroxide should be at least 80 percent pure, containing only traces of sulphates, chlorides, nitrates, or silicates, and should be soluble in alcohol.

In preparing the soap solution, an excess of potassium hydroxide is dissolved in a mixture of 7 parts by volume of alcohol and 3 parts of water. Aliquot samples of the solution are standardized against normal hydrochloric acid and sufficient alcohol and water are added to obtain a concentration of 24.5 to 25 g of potassium hydroxide in 100 cc. Then 10 parts of the alcoholic potash are mixed with 55 parts by volume of castor oil and heated in a closed kettle with constant agitation until the temperature of the mixture has been at 200° F. (93.3° C.) for 2 hours. When the alcoholic soap is completed it should have the following composition by weight:

	Percent
Nonvolatile constituents:	
Castor oil	83. 2
Potassium hydroxide	3. 7
Total	86. 9
Volatile constituents:	
Alcohol	8. 6
Water	4. 5
Total	13. 1

When the soap has cooled, it is mixed with an equal volume of carbon disulphide and agitated until the mixture is honogeneous..

TOXICITY OF CARBON DISULPHIDE VAPOR TO THE DIFFERENT STAGES OF THE JAPANESE BEETLE

It was early found in the experimental work that carbon disulphide was one of the most effective fumigants used against the Japanese beetle (*27*). All stages succumbed when exposed in an atmosphere containing the vapor. The speed of fatal reaction appeared to be governed by the concentration of the vapor and the activity of the insect. No study has been made to determine definitely the manner in which this chemical kills the different stages, but it probably kills by dissolving the fatty tissue, coagulating the proteins, interrupting the assimilation of oxygen (*127*), and disrupting the vital processes.

MINIMUM CONCENTRATION OF VAPOR LETHAL TO DIFFERENT STAGES

The minimum concentration of carbon disulphide vapor lethal to the different stages of the Japanese beetle was determined at a temperature of 80° F. and with an exposure of 2 hours. The different stages were removed from soil and placed in special cages for treatment. The eggs were placed in glass tubes, each end of which was

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closed by an 80-mesh wire cap (fig. 1, *A*), the larvae and pupae in wire-covered cross-section cages (fig. 1, *B*), and the adults in cages like that shown in figure 1, *C*. The insects were then placed in 22-liter bell jars, and the desired quantity of carbon disulphide, which was measured in a serological pipette graduated in 0.01 cubic centimeter subdivisions, was dropped on absorbent cotton so placed in the bell jars that the insects were subjected to the vapor without coming into contact with the liquid. At the end of the predetermined period of time, the insects were removed from the bell jars and placed in special containers for observation. The eggs were placed on the surface of moist leaf mold, in indentations on a plaster block as shown in figure 2, *A*, the larvae and pupae on the surface of soil in cross-section trays (fig. 2, *B*) and the adults in wire cages with food.

It was necessary to extend the observation of the treated insects over a period of several days in order to determine with a fair degree of accuracy the mortality caused by each treatment. An egg was kept under observation until it hatched or decomposed. Larvae, pupae, and adults were considered to be dead only when there was evidence of discoloration and disintegration of the tissue. When adults were only slightly affected by the vapor, they usually resumed feeding within a few hours; uninjured larvae soon burrowed into the soil. It often occurred that the movements of the larvae, pupae, and adults were so slight after treatment as to require a hand lens for detection. If these doubtful individuals were touched with a blunt instrument, the movement of the legs, mouth parts, or body was usually amplified to such an extent as to be readily discernible. The degree of thigmotropic response was dependent upon the severity of the treatment, the stage of revival, and the development of the insect. In view of the delayed recovery of the insects after some of the treatments, it was important that the period of observation be of sufficient duration to permit the recovery of all insects not killed. This phase of insecticidal investigation with fumigants is important and has received the attention of several investigators, among whom might be mentioned Swain (*140*), Neifert and Garrison (*107*), Neifert et al. (*106*), Hamlin and Reed (*52*), and Strand (*139*). With the Japanese beetle, the effect of a treatment on the larvae or adults could usually be determined definitely at the end of 5 days, pupae had to be kept under observation for 15 days, and eggs for 30 days.

The lowest concentration of carbon disulphide that consistently killed all of a given stage in successive tests was considered to be the minimum lethal concentration. A graphic presentation of the minimum concentration of the vapor lethal to each stage is given in figure 3.

The egg is the stage most resistant to the action of the vapor, probably because it is immotile and protected by a thick, almost impermeable membrane. When the larva emerges from the egg, it is active and more easily affected by the vapor. The concentration required depends upon the activity of the stage, the more active the stage, the lower the concentration required. The adult, which is the most active, is the most susceptible and the pupa, which is not motile, is the least susceptible of the postembryonic stages. A concentration of 160 mg per liter at a temperature of 80° F., destroyed all of the adults and some of the other stages within a period of 2 hours,

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but a concentration of 600 mg per liter was required to kill all stages of the insect under these conditions.

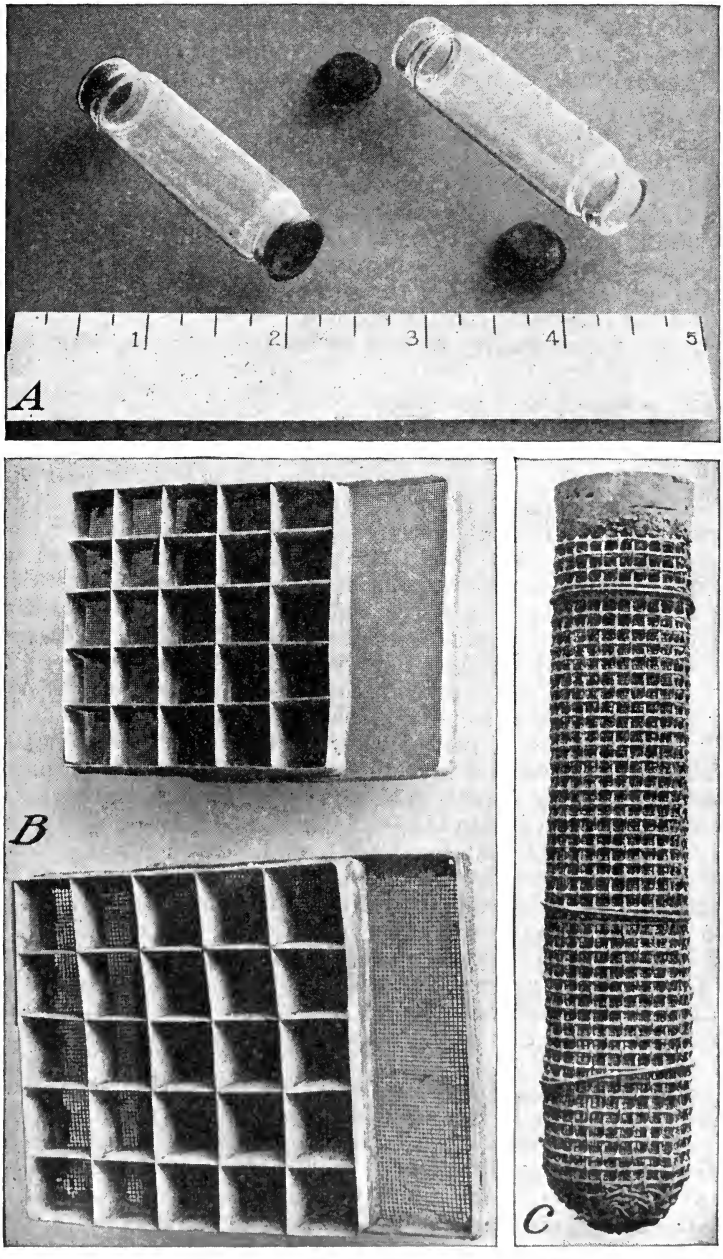

FIGURE 1.—Cages used for the stages of the Japanese beetle in fumigation experiments: *A*, For eggs; *B*, for larvae and pupae; *C*, for adults.

EFFECT OF TEMPERATURE ON THE MINIMUM LETHAL CONCENTRATION OF VAPOR

The concentration of vapor that is fatal to any stage of the Japanese beetle is not a fixed proportion but fluctuates with the temperature

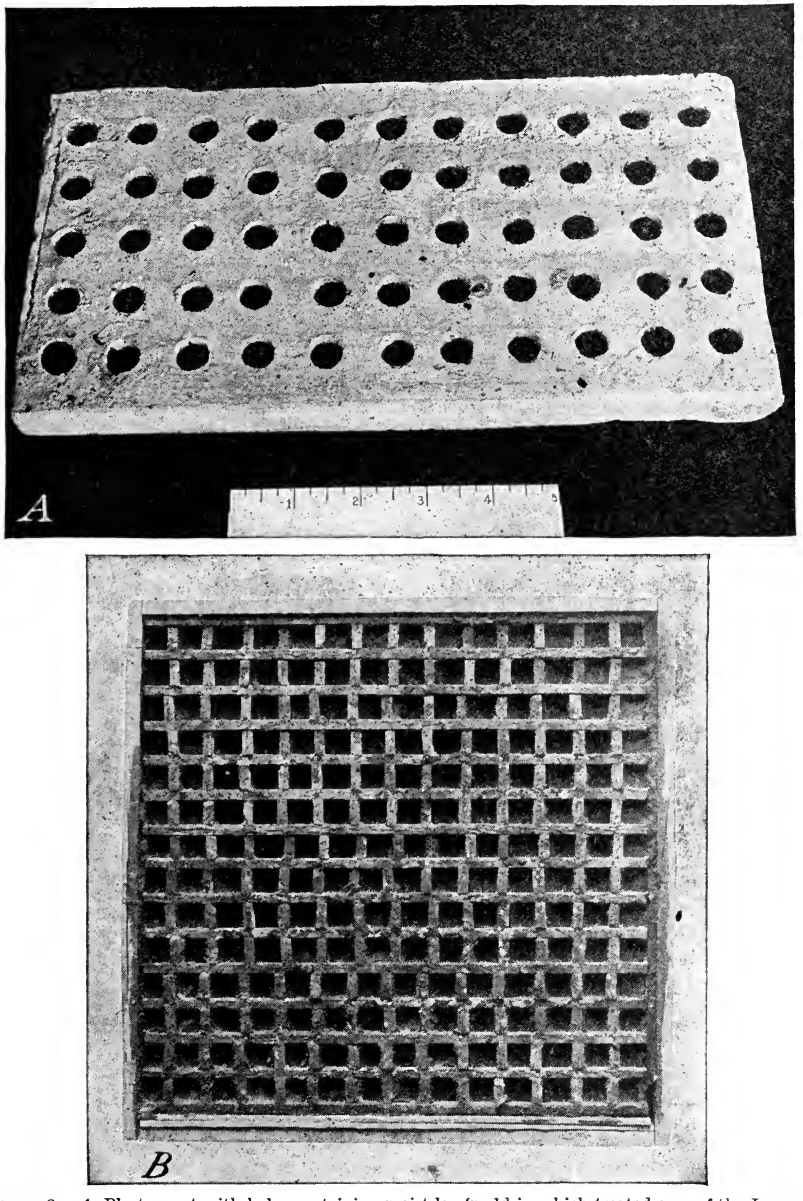

FIGURE 2.—*A*, Plaster cast with holes containing moist lea fmold in which treated eggs of the Japanese beetle were placed for observation after being subjected to the fumigant; *B*, cross-section tray in which larvae and pupae were placed for observation.

and the period of exposure. The effect of temperature is most apparent with the shorter exposures. The general effect of increasing temperature is to accelerate the activity of the insect and speed up the rate at which the poisonous vapor is absorbed, thus making it possible to kill with lower concentrations. The effect of the tem-

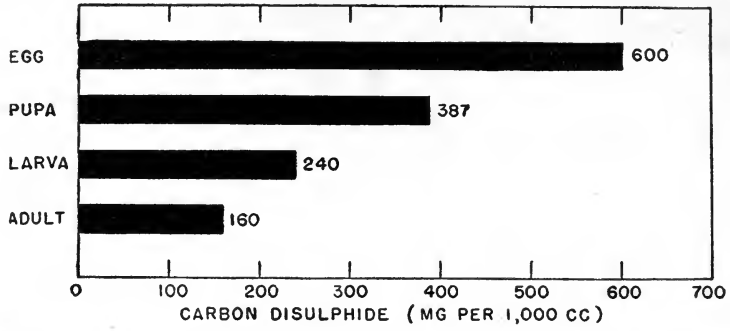

FIGURE 3.—Minimum concentrations of carbon disulphide vapor lethal to the different stages of the Japanese beetle, with an exposure of 2 hours at 80° F.

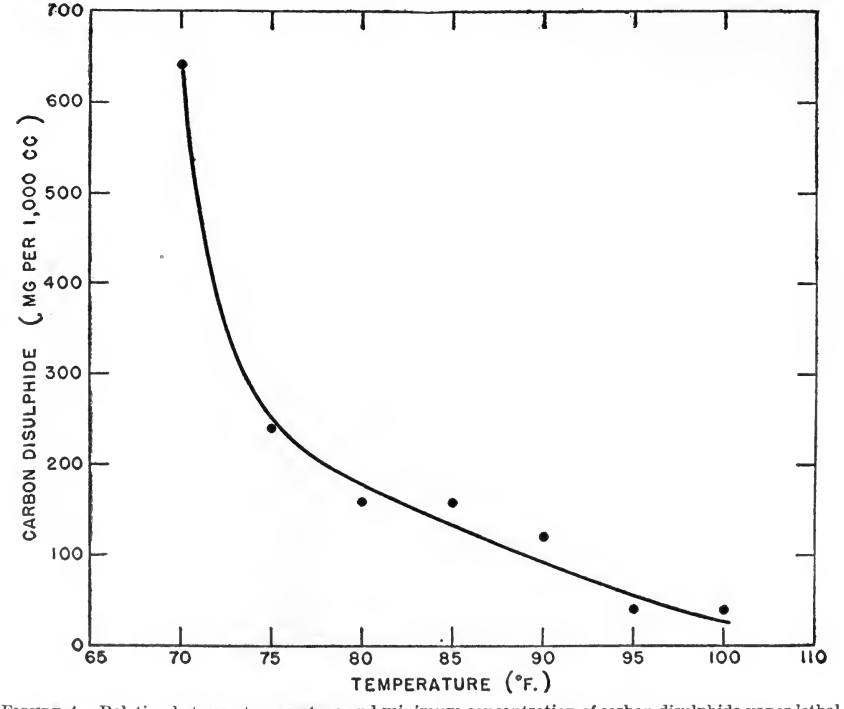

FIGURE 4.—Relation between temperature and minimum concentration of carbon disulphide vapor lethal to the adult Japanese beetle with an exposure of 2 hours.

perature on the minimum concentration effective against the adult beetle is shown in figure 4, where the concentrations required to kill within a period of 2 hours are seen to range from 640 mg per liter at a temperature of 70° F. to 30 mg at 100°. It will be observed that

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when the temperature falls below 75° the concentration of vapor required increases rapidly. From the nature of this curve, it appears that a temperature of 75° is the minimum for practical fumigation to destroy the adult beetle within this period.

A more detailed study of the insecticidal action of carbon disulphide vapor in relation to the time-temperature-concentration complex was made with third-instar larvae. Tests were made with different concentrations at temperatures ranging from 40° to 100° F. for periods

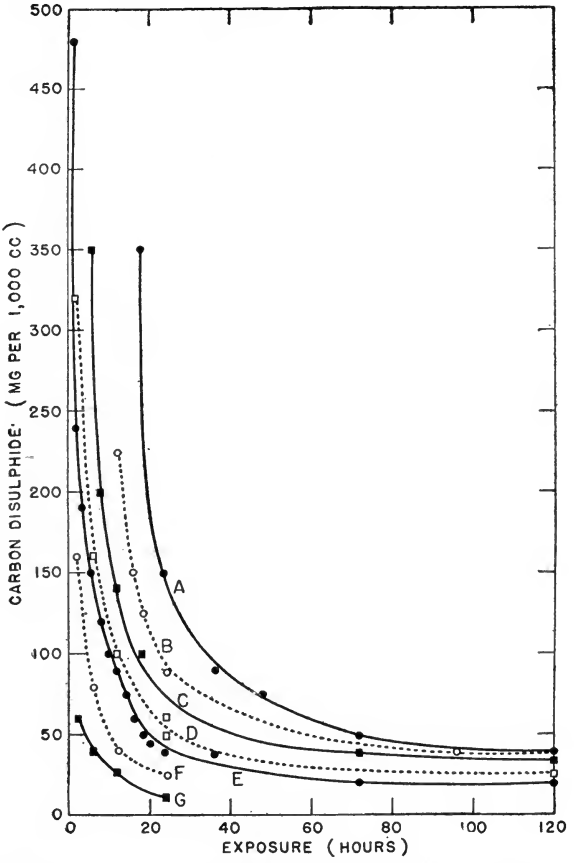

FIGURE 5.—Concentration of carbon disulphide vapor needed at different temperatures and periods of exposure to kill third-instar larvae of the Japanese beetle: *A*, 40°; *B*, 50°; *C*, 60°; *D*, 70°; *E*, 80°; *F*, 90°; *G*, 100° F.

from one-half hour to 120 hours. In view of the large number of minimum concentrations that might be determined, all the possible relations have not been tested, but a sufficient number of the critical points have been determined to draw lethal concentration curves for each temperature. The minimum concentrations determined as effective against the larvae at different temperatures for the various exposures are shown in table 2, and the curves drawn from these are given in figure 5.

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TABLE 2.—*Concentration of carbon disulphide vapor needed at different temperatures and periods of exposure to kill third-instar larvae of the Japanese beetle*

Exposure (hours)	Minimum effective concentration per liter at temperature of—						
	40° F.	50° F.	60° F.	70° F.	80° F.	90° F.	100° F.
	Mg	*Mg*	*Mg*	*Mg*	*Mg*	*Mg*	*Mg*
½					1,440		
1½					480		
2				320	240	160	60
4					190		
6			350	160	150	80	40
8			200		120		
10					100		
12		225	140	100	90	40	25
14					75		
16		150			60		
18	350	125	100		50		
20					45		
24	150	90	60	50	40	25	10
36	90				40		
48	70						
72	50		40		20		
96		40					
120	40	40	35	25	20		

It will be observed that with each curve as it approached the vertical great differences in concentration affect very slightly the time required to obtain a complete kill, whereas along the portions of the curves approaching the horizontal small differences in concentration correspond to great differences in time. These curves are similar to those obtained by Powers (*113*) and Gersdorff (*43*) in their toxicity studies with goldfish. From a consideration of the portion of each curve approaching the vertical, it appears that the minimum periods effective in killing the larvae were 20 hours at 40° F., 12 hours at 50°, 6 hours at 60°, 4 hours at 70°, 2 hours at 80°, and less than 2 hours at temperatures in excess of 80°. From the nature of these curves it appears improbable that the minimum period of exposure at a given temperature could be materially reduced even with greatly increased concentrations.

When the portions of the curves approaching the horizontal are considered, it is apparent that the minimum effective concentrations per liter were 40 to 50 mg at 40° F., 35 to 45 mg at 50°, 35 to 40 mg at 60°, 25 to 30 mg at 70°, 15 to 20 mg at 80°, 10 to 15 mg at 90°, and 5 to 10 mg at 100°.

It is possible from these curves to estimate the minimum temperature required for the vapor to kill the larvae within a given period. If the period of exposure was limited to 12 hours, it is apparent that a minimum temperature of 50° F. would be required, whereas, if the exposure was limited to 2 hours, it would be necessary to have the temperature at 80°. When it is possible to prolong the period that the larvae are in contact with the vapor for more than 20 hours, the larvae can be destroyed at all temperatures of 40° or more.

EFFECT OF RELATIVE HUMIDITY ON THE MINIMUM LETHAL CONCENTRATION OF VAPOR

A preliminary experiment was conducted to determine whether the relative humidity of the air at a temperature of 80° F. modified the minimum concentration of the vapor required to kill third-instar larvae within a period of 24 hours. The air in the bell jars was conditioned to a definite relative humidity by circulating the air through

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saturated salt solutions, as recommended by Headlee (*55*), for 24 hours before introducing the larvae and the carbon disulphide. It was found that the minimum lethal concentration of 40 mg per liter at this temperature was not modified by varying the relative humidity from 1 percent to 100 percent. It appears that the relative humidity of the atmosphere has little influence on the insecticidal action of carbon disulphide vapor.

EFFECT OF PRESSURE ON THE MINIMUM LETHAL CONCENTRATION OF VAPOR

Experiments were conducted in a special vacuum and pressure tank, constructed to maintain a pressure from approximately absolute vacuum to 150 pounds per square inch, to determine the effect of pressure on the minimum concentration effective in killing the adult beetle within a period of 2 hours at a temperature of 70° F. Tests were completed at pressures ranging from 254 to 760 mm of mercury, but the tank was destroyed by an explosion before the tests with pressures above 760 mm could be completed. The following results were obtained with a concentration of 80 mg of carbon disulphide per liter:

Pressure, mm of mercury:	*Mortality percent*
254	100
500	75
760	35

Since it required a concentration of 640 mg of carbon disulphide per liter to kill adult beetles within a period of 2 hours at a temperature of 70° at normal pressure, it is apparent that the effectiveness of the vapor is considerably increased at reduced pressures, for 80 mg was sufficient at a pressure of 254 mm. The increase in mortality cannot be attributed to the fact that the beetles were deprived of the normal concentration of oxygen in the air because adult beetles were apparently unffected when the pressure was reduced to 254 mm for a period of 16 hours. The increase in effectiveness at reduced pressures is probably due to increased absorption of the vapor by the insect.

EFFECT OF LIGHT ON THE MINIMUM LETHAL CONCENTRATION OF VAPOR

It has been generally recognized that plants that are fumigated in direct sunlight, or that are exposed to the sun within a few hours after treatment, are especially subject to injury because the stomata permit the entrance of more gas into the tissues than is the case when the plants are in the dark. The presence or absence of light appears to have no effect on the concentration of vapor lethal to the different stages of the Japanese beetle.

EFFECT OF THE PURITY OF CARBON DISULPHIDE ON THE TOXICITY OF THE VAPOR

It was thought possible that the degree of purity of the carbon disulphide might influence the toxic action of the chemical on the Japanese beetle. Comparative tests were made of a chemically pure grade and a commercial grade at a temperature of 70° F. and with an exposure of 24 hours. These two grades were analyzed according to the procedure of Collins et al. (*12*) with the results shown in table 3.

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TABLE 3.—*Comparison of C. P. and commercial grades of carbon disulphide*

Item	C. P. grade	Commercial grade
Boiling range	46°–47° C.	45°–48° C.
Nonvolatile matter	0.001 percent	0.016 percent.
Foreign sulphides	None	Present.
Sulphates and sulphites	do	Do.
Water	do	Trace.

The relative effectiveness of the chemically pure and the commercial grades of carbon disulphide is shown in figure 6.

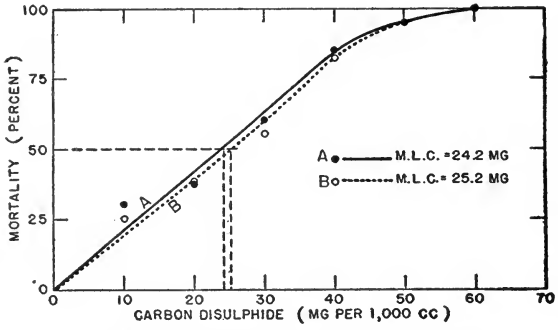

FIGURE 6.—Effect of the purity of carbon disulphide on the toxicity of the vapor to third-instar larvae of the Japanese beetle: *A*, Chemically pure grade; *B*, commercial grade. The median lethal concentrations are indicated.

It was decided to compare the toxicity of these two grades by comparing the median lethal concentrations, because, as Fisher stated in a note to Tattersfield and Morris (*141*), the most accurate comparison in toxicity can be made when a mortality of 50 percent is the standard of comparison. Tattersfield and Morris used this point, and it has also been shown experimentally by Strand (*139*) and Trevan (*149*) that the closest agreement in duplicate insecticide tests occurred when 50-percent death points were selected as criteria of toxicity.

The median lethal concentration of the chemically pure grade was 24.2 mg and that of the commercial grade was 25.2 mg, indicating that there was no significant difference in the insecticidal value. This agrees with the conclusion of Cory (*15*) from the results of his tests with different grades of carbon disulphide against the eggs of the Angoumois grain moth (*Sitotroga cerealella* Oliv.).

TOXICITY OF CARBON DISULPHIDE EMULSION TO THE DIFFERENT STAGES OF THE JAPANESE BEETLE

COMPARATIVE TOXICITY OF CARBON DISULPHIDE AS VAPOR AND IN EMULSION

A study was made to determine the comparative toxic value of the vapor and the emulsion at a temperature of 70° F. Different concentrations of the emulsified form were prepared by adding water to a stock emulsion made according to formula 7 (p. 12). Third-instar larvae were removed from soil and exposed to different concentrations of the vapor and of emulsions of carbon disulphide for a period of 24 hours. The mortality obtained with each concentration of the vapor and of the emulsion is given in figure 7.

It was found that the median lethal concentration (m. l. c.) of the vapor was 32 mg per liter and the medial lethal concentration of the emulsified form was 65 mg per liter. It appears that carbon disulphide, when in an emulsion, has about half the toxic value of the same

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quantity in the form of vapor. The lower toxic value of the emulsified carbon disulphide may be attributed to the lowered volatility of the compound and to the relative inactivity of the larvae when submerged.

MINIMUM CONCENTRATION OF EMULSION LETHAL TO DIFFERENT STAGES

The minimum concentrations of emulsified carbon disulphide required to kill the eggs, larvae, and pupae of the Japanese beetle were determined at a temperature of 70° F. The insects were removed from soil, placed in the special cages used in the study of the toxicity of the vapor of carbon disulphide, and submerged in 20 liters of emulsions of different concentrations for a period of 24 hours. The emulsions of different concentrations were prepared by adding water to the stock emulsion of formula 10. A summary of the minimum effective concentrations required for each stage is given in figure 8.

A concentration of 1,250 mg of carbon disulphide per liter of emulsion was the lowest that prevented all of the eggs from hatching. A concentration of 625 mg was sufficient to kill the pupae and 375 mg the larvae. It has been shown (fig. 5, *D*) that 50 mg of carbon disulphide vaporized in 1 liter of air is sufficient at 70° F. to kill all third-instar larvae in an exposure of 24 hours. The fact that 375 mg in an equal volume of emulsion is necessary to produce the same mortality shows that emulsification has decreased to about one-seventh the insecticidal efficiency of the compound on the basis of 100-percent mortality.

EFFECT OF TEMPERATURE ON THE MINIMUM LETHAL CONCENTRATION OF EMULSION

As was the case with the vapor, the concentration of carbon disulphide in an emulsion that is fatal to the different stages of the beetle fluctuates with the temperature and the period of exposure. A summary of the minimum concentrations required to kill third-instar larvae, when removed from soil and submerged for 24 hours, is given in figure 9.

The minimum lethal concentration was found to decrease progressively from 1,000 mg to 100 mg as the temperature was increased by 5-degree increments from 40° to 90° F.

The effect of the period of submersion on the minimum lethal concentration of carbon disulphide emulsion was studied at a temperature of 70° F. with third-instar larvae and eggs which were removed from soil and submerged in different concentrations of emulsified carbon disulphide for periods ranging from three-fourths of an hour to 24 hours. A summary of the minimum concentrations required to kill the eggs and larvae when submerged for different periods is given in figure 10.

It is apparent in the case of the larvae that when the carbon disulphide content is decreased below 500 mg per 1,000 cc, the period of submersion must be lengthened rapidly and that when the period of submersion is reduced below 7 hours, the concentration must be increased greatly to kill the larvae. The eggs are more resistant than the larvae to the emulsion. When the concentration of carbon disulphide is decreased below 2,200 mg, the period of submersion must be increased materially to kill the eggs.

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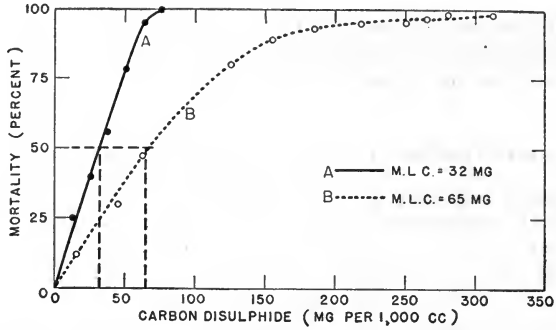

FIGURE 7.—Comparative toxicity of carbon disulphide as vapor and in emulsion at various concentrations as affecting third-instar larvae of the Japanese beetle, removed from soil, after an exposure of 24 hours at 70° F.: *A*, Vapor; *B*, emulsion. The median lethal concentrations (m. l. c.) are indicated.

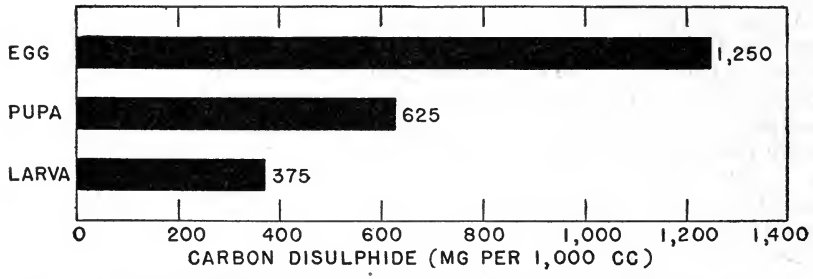

FIGURE 8.—Minimum concentration of carbon disulphide emulsion lethal to the immature stages of the Japanese beetle removed from soil and submerged for 24 hours at 70° F.

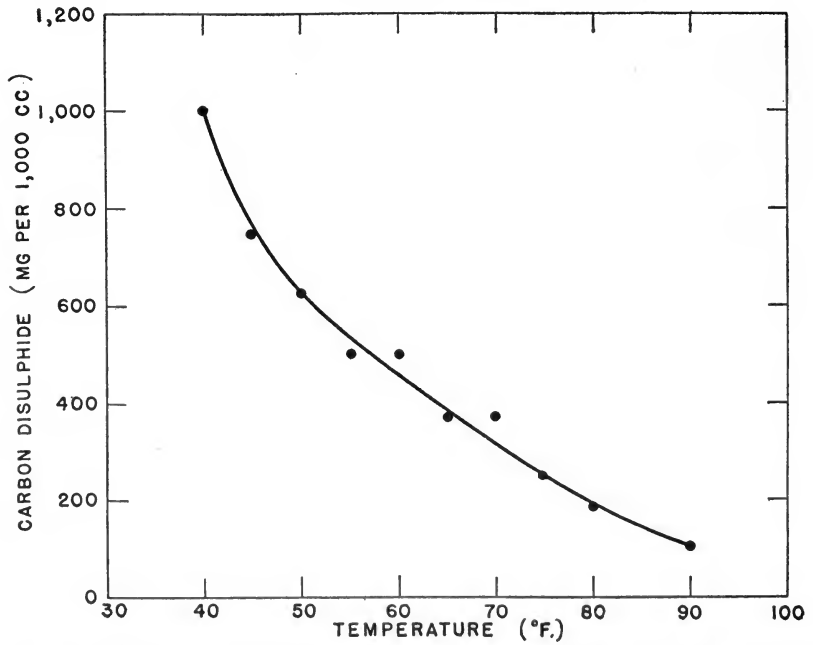

FIGURE 9.—Relation between temperature and minimum concentration of carbon disulphide emulsion lethal to third-instar larvae removed from soil and submerged for 24 hours.

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EFFECT OF THE EMULSIFIER ON THE TOXICITY OF EMULSIFIED CARBON DISULPHIDE

It was realized that the type of the emulsifier might modify the insecticidal action of carbon disulphide. A study was therefore made to determine the relative toxicity of carbon disulphide when emulsified with different agents. The emulsifiers used were sodium oleate-rosin soap (formula 5), sodium oleate-rosin-beta-naphthol soap (formula 6), potassium-oleate soap (formula 7), castor-oil soap (formula 10), cottonseed-oil soap (formula 12), coconut-oil soap (formula 13), peanut-oil soap (formula 14), corn-oil soap (formula 15), and palm-oil soap, which was made by substituting palm oil for coconut oil in formula 13. Groups of larvae were removed from soil and submerged in these emulsions, each prepared in a series containing 125, 250, 375, and 500 mg of carbon disulphide per liter, for a period of 24 hours at a temperature of 58° F. Groups of larvae were also submerged in the concentration of each emulsifier that had been used with 500 mg of carbon disulphide. The emulsifiers at these concentrations were not toxic to the larvae. The average mortalities, in percent, and the median lethal concentrations (m.l.c.) obtained with the different emulsions are shown in figure 11.

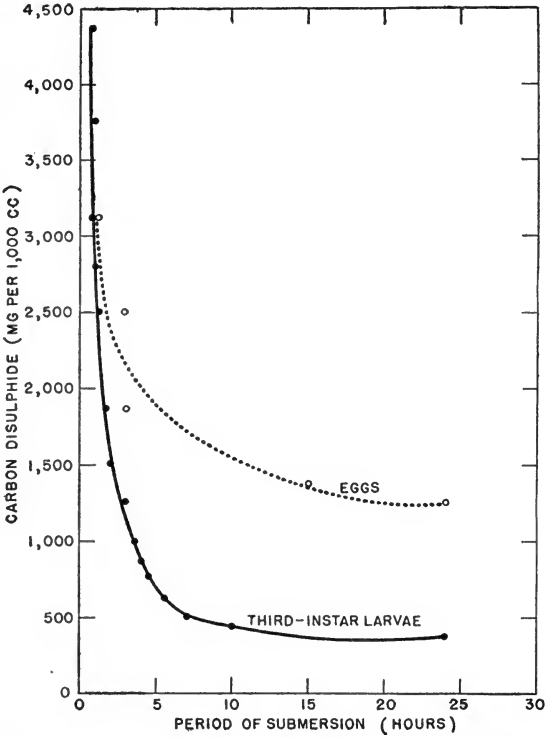

FIGURE 10.—Concentration of carbon disulphide emulsion needed at different periods of submersion to kill third-instar larvae and eggs at 70° F. when removed from soil.

A study of these curves shows that the emulsion containing sodium oleate-rosin-beta-naphthol soap emulsifier was considerably less toxic than the other emulsions. The results obtained with most of the emulsifiers indicate that there is little difference in their insecticidal value. Equally as good results might be expected with emulsions containing sodium oleate-rosin soap, cottonseed-oil soap, peanut-oil soap, castor-oil soap, and palm-oil soap, and probably slightly poorer results with emulsions containing corn-oil soap, potassium-oleate soap, and coconut-oil soap. The results of this study emphasize the importance of the emulsifier and show that the composition of the

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emulsifier should not be modified without determining the effect of the change on the insecticidal value of the emulsion.

For insecticidal work in commercial nurseries, the emulsion containing castor-oil soap as an emulsifier (formula 10) appeared to be more satisfactory from a physical viewpoint than the emulsion made with sodium oleate-rosin soap (formula 5). It was believed that the difference in the toxic value of these two emulsions was not of practical significance, but in order to obtain more extensive data, comparative tests were made with them over a period of 2 years. In carrying out these tests, larvae were removed from soil and submerged at room temperatures in different concentrations of these emulsions.

The emulsions made with castor-oil soap had on the average 98.7 percent of the effectiveness of those made with sodium oleate-rosin

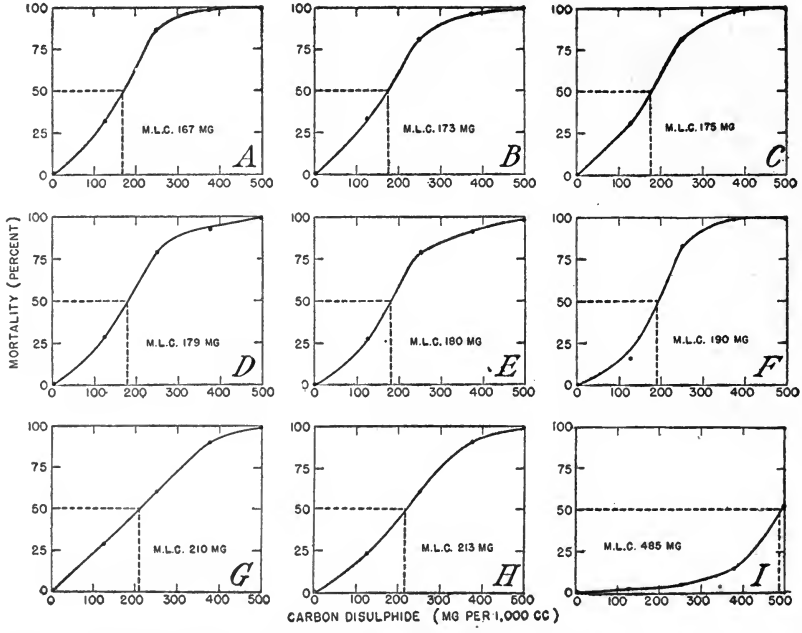

FIGURE 11.—Toxicity to larvae of the Japanese beetle of emulsions of carbon disulphide prepared with different emulsifiers; larvae removed from soil and submerged for 24 hours at 58° F. in emulsions prepared with sodium oleate-rosin soap (*A*); cotton-seed-oil soap (*B*); peanut-oil soap (*C*); castor-oil soap (*D*); palm-oil soap (*E*); corn-oil soap (*F*); potassium oleate soap (*G*); coconut-oil soap (*H*); sodium-oleate-rosin-beta-naphthol soap (*I*). The median lethal concentrations (m. l. c.) are indicated.

soap. The relative effectiveness ranged from 92 to 108 percent in tests made with concentrations from 125 to 3,750 mg per liter, but the concentrations used seemed to bear no relation to the percentage of effectiveness, and the greater number of cases clustered closely about the average. It is evident that this difference between the two emulsions is not of practical significance.

It was believed that the slight difference in the toxic value of these emulsions might be due to the difference in the rate of evaporation of carbon disulphide. A series of stock emulsions was made with the sodium oleate-rosin soap and with the castor-oil soap with the ratios of the emulsifier to carbon disulphide of 3:7, 1:1, and 7:3. Dilutions were prepared from these stock emulsions so as to contain 1.25 g

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of carbon disulphide per liter. One-half liter of each of these dilute emulsions was put in a wash bottle at a temperature of 70° F., and 1,000 cc of air at the same temperature was slowly bubbled through it at the rate of 1 liter in 2 hours. The bubbling of air in each test was carefully controlled so that the experiments would be comparable. The quantity of carbon disulphide removed from each emulsion was determined by passing the air through alcoholic potassium hydroxide and analyzing the solution by the iodometric procedure. The quantity of carbon disulphide vaporized, expressed as the percent of the quantity in the emulsions, is given in figure 12.

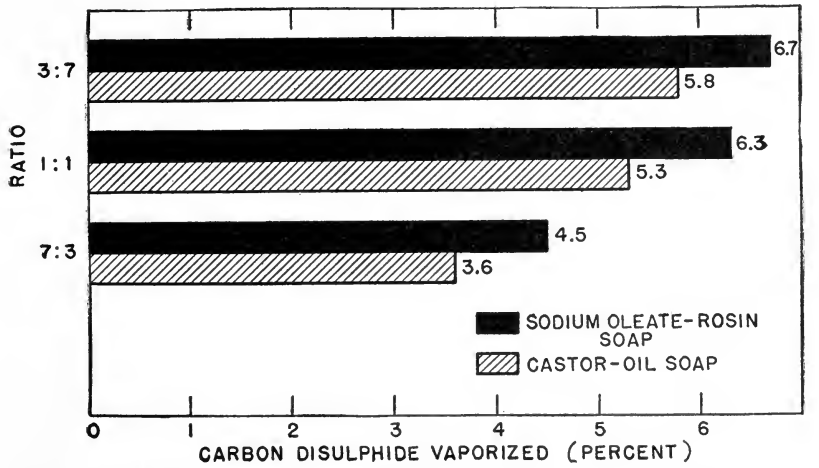

FIGURE 12.—The effect of the ratio of emulsifier to carbon disulphide by volume on the volatility of carbon disulphide.

It is seen that the rate of evaporation of carbon disulphide from the dilute emulsions is influenced by the type of the emulsifier and by the ratio of the emulsifier to the carbon disulphide in the mixture. The emulsions in which the proportion of the emulsifier to the carbon disulphide is relatively small lose the chemical more rapidly than those in which high proportions of emulsifier are present. The carbon disulphide vaporized more readily from the emulsions containing sodium oleate-rosin soap as the emulsifier than from those containing castor-oil soap, which probably accounts for the slightly higher toxic value of the former emulsions.

A consideration of the different experiments shows that the insecticidal value of carbon disulphide is dependent to a large extent upon the time-temperature-concentration complex. It may be possible to arrange these factors so that the insect can be destroyed within the range of tolerance of the plants. The treatment of each commodity is an individual problem, and the arrangment of these factors must be governed by the environmental conditions.

EFFECT OF CARBON DISULPHIDE ON THE SOIL

It was observed as far back as 1877, by Oberlin (*108*), that treatment of soil with carbon disulphide to destroy insect pests had a stimulating effect on the subsequent growth of plants. Many investigators have searched for a satisfactory explanation of this better growth of

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plants in sterilized soils, and many theories have been advanced, but it appears to be established that the use of soil disinfectants may result in (1) a partial destruction of the soil fungi (*154, 157*), actinomycetes (*63, p. 491; 157*), nitrifying organisms (*35, 36, 121, 122, 137, 138*), protozoa (*10, 92, 118, 122*), and worms (*120*); (2) a decrease in the number of bacteria in the soil followed by a sustained increase (*35, 36, 50, 63, 121, 122*); (3) an accumulation of ammonia (*36, 77, 119, 123*); (4) a temporary reduction of nitrates (*48, 157*); (5) a temporary increase in carbon dioxide (*150, 157*); and (6) an increase in the oxidizing power of the soil (*16*).

In view of the great commercial value of the ornamental and greenhouse plants that are grown and the fact that the soil about their roots must be free of living stages of the Japanese beetle before they can be shipped out of the restricted area, it is important to know whether the concentrations of carbon disulphide employed against this insect are sufficient to cause any of the above changes in the soil. It was decided to determine the effect of the average insecticidal dosage of carbon disulphide on the number of micro-organisms and on the accumulation of ammonia and nitrates in the soil.

It is realized that, under certain conditions, there may be no relationship existing between the number of micro-organisms, or the accumulation of the products of their metabolism, and the growth of higher plants, since factors other than the supply of nitrogenous matter and the decomposition of plant residues may influence plant development; but it is believed that, in general, stimulation in the development of micro-organisms and an increase in nitrogenous matter would have a beneficial effect on higher plants. A preliminary report on the microbiological study of sandy loam after treatment with carbon disulphide to destroy the Japanese bettle has been published by the senior author (*31*).

EFFECT OF CARBON DISULPHIDE VAPOR ON SOIL

A quantity of loamy sand, sifted to remove stones and mixed to make it homogeneous, was divided into 4½-pound samples and put into jars. Carbon disulphide was injected into these samples in doses equivalent to 1 pound to a cubic yard, and the jars were sealed for 48 hours. The covers were then removed and sterile cotton plugs inserted to permit the vapor to escape without subjecting the soil to possible contamination by bacteria and fungi normally present in the atmosphere. The samples were kept at room temperature, and sterile distilled water was added as required to replace that lost by evaporation. The number of bacteria and fungi and the quantity of ammonia and nitrates in the soil were determined both before the soil was treated with carbon disulphide and 7, 33, 66, and 112 days after treatment. The method used in determining the number of bacteria in the soil is that given by Waksman and Fred (*156*). The number of fungi in the soil was determined by a similar method, the special medium recommended by Waksman (*155*) being employed. The nitrates were determined colorimetrically with phenol disulphonic acid, and the ammonia was distilled from soil into standard sulphuric acid and determined by titration according to the procedures described by Fred (*37*). The effect of fumigating soil with this dosage is summarized in figure 13.

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It is apparent that this small dosage of carbon disulphide stimulated the fungi, as was also reported by Oldenbusch (*109*). There was little change in the number of bacteria, as was expected in view of the observations by Gainey (*39*). The fungous flora was simplified by the treatment and consisted largely of species *Zygorhynchus* and of *Penicillium*. The treatment had no effect on the nitrates in the soil but resulted in an accumulation of ammonia.

It has been the practice of certain greenhouse men to leave the soil fumigated with carbon disulphide in the boxes and bins until used for potting plants. This permits the vapor to remain in contact with the soil for relatively long periods. As under some conditions the prolonged contact with the vapor may be detrimental to some of the beneficial micro-organisms in the soil, it is advisable to aerate the soil after fumigating for the required period.

EFFECT OF CARBON DISULPHIDE EMULSION ON SOIL

Loamy sand placed in large cylinders with the openings at the bottom covered with muslin was treated with dilute carbon

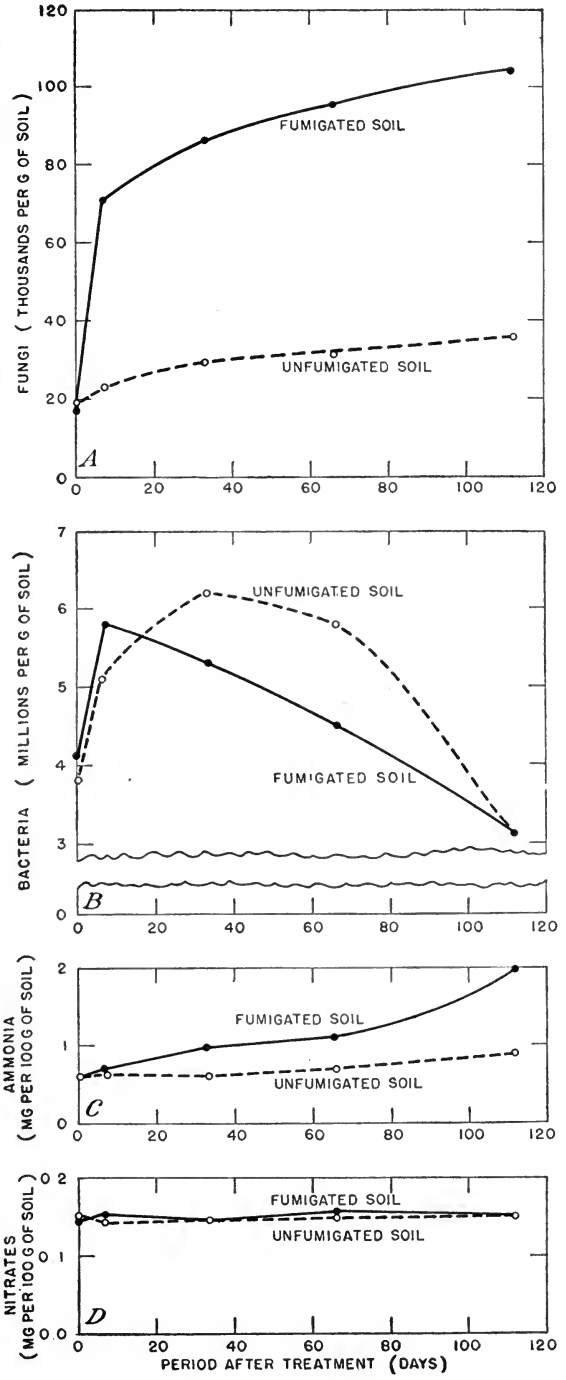

FIGURE 13.—Effect of carbon disulphide vapor on soil, when the liquid was injected in the proportion of 1 pound to the cubic yard: *A*, Effect on the number of fungi; *B*, effect on the number of bacteria; *C*, effect on the ammonia concentration; *D*, effect on the nitrate concentration.

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disulphide emulsion, containing 625 mg of carbon disulphide per liter, by pouring on the surface a volume of liquid equivalent to that of the soil and allowing it to percolate through the mass. A second series was treated with an equal volume of water, and a third series remained untreated. After 3 days the soils were spread out and dried until the moisture was at about 50 percent saturation. They were then placed in jars and maintained at this degree of moisture by the addition of distilled water as required. The number of bacteria and fungi and the quantity of ammonia and nitrate in the soil were determined both before the soil was treated and at intervals up to 150 days after treatment. The results of these determinations are summarized in figure 14.

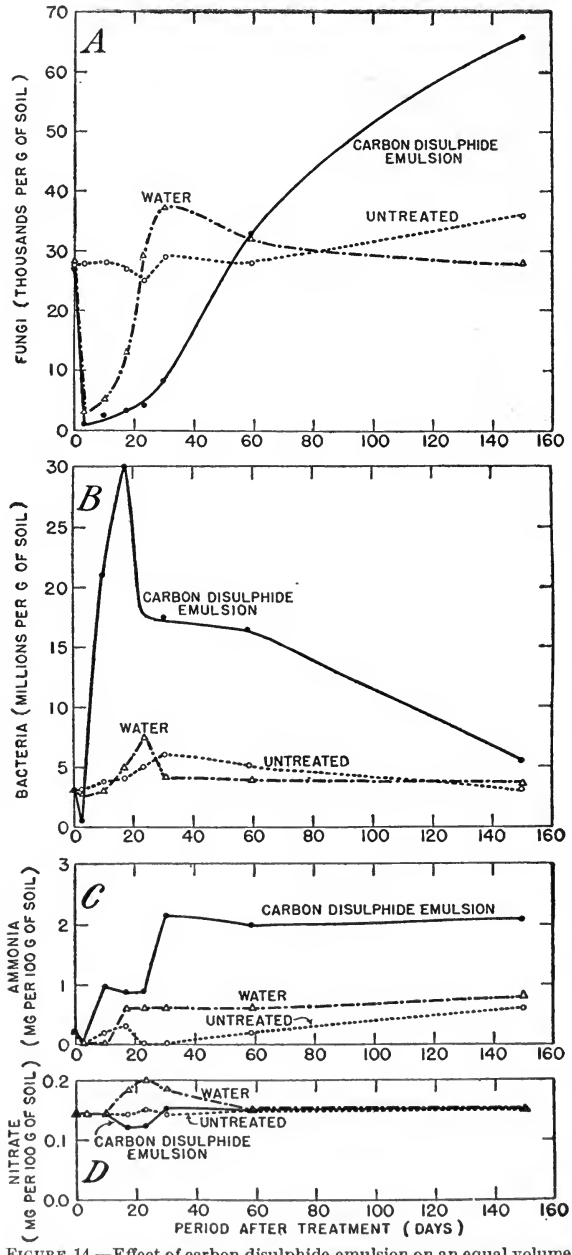

FIGURE 14.—Effect of carbon disulphide emulsion on an equal volume of soil: *A*, Effect on the number of fungi; *B*, effect on the number of bacteria; *C*, effect on the ammonia concentration; *D*, effect on the nitrate concentration.

The treatment of the soil with the dilute emulsion almost eliminated the fungi. It is probable that this condition was brought about largely by the water-logged condition of the soil because the reduction in the number of fungi in the soil treated only with water was nearly as extensive. The number of fungi in the soil treated with water returned to normal in 21 days. The fungi in the soil treated with the emulsion recovered more slowly but at the end of 150 days were about twice the number in the untreated soil.

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The bacteria appeared to be unaffected by the application of water. The emulsion reduced the number of bacteria during the first 3 days following treatment. When the emulsion-treated soil began to dry the bacteria increased rapidly so that at the end of 17 days there were almost 10 times the initial number. Then the number of bacteria decreased progressively until at the end of 150 days there was little difference between the number in this soil and in the untreated soil. Neither the application of emulsion nor of water to the soil had any effect on the nitrates but resulted in an increase in the quantity of ammonia in the soil.

It appears from these preliminary results that fumigation of soil with carbon disulphide at the rate of 1 pound to a cubic yard for a period of 48 hours and the application of dilute emulsions of the chemical have no permanent detrimental effect, and probably so modify the organic matter in the soil as to make it more available for higher plants.

EFFECT OF CARBON DISULPHIDE ON VEGETATION

It was early found by Marion (*96, 97*), Vermorel (*153*), and other investigators that direct contact of liquid carbon disulphide with the roots almost invariably proved fatal to plants, and early experimenters were somewhat discouraged by the injury thus caused. Rogers and Hatfield (*117*), in fact, have utilized the destructive action of this chemical on plants to eradicate perennial weeds, such as wild morning-glory (*Ipomoea pandurata*), perennial peppergrass (*Lepidium draba*), Russian knapweed (*Centaurea picis*), Canada thistle (*Cirsium arvense*), and milkweed (*Asclepias syriaca*) in fields in Colorado. In the experimental work with injections of liquid carbon disulphide to destroy the Japanese beetle in soil about the roots of growing plants, a practice which will be discussed later, it was found impossible to inject the chemical in insecticidal concentration at any season when the soil conditions were favorable without causing serious injury to the plants, although it has been found possible to use carbon disulphide in an emulsion about the roots of growing plants to destroy immature stages of this insect. Results similar to those obtained with emulsions have been reported by Leach (*78*) and Townsend (*147, 148*) with aqueous solutions of carbon disulphide in their experiments to control the root aphid on apple. This is probably due to the more uniform dispersion of the chemical in soil by water than is obtained by the diffusion of the vapor. The reaction of plants to carbon disulphide about their roots is apparently dependent upon the concentration of the chemical, the period it is in contact with the roots, the vigor and the variety of the plant, and the condition of the soil. In general, the application of a dilute emulsion of carbon disulphide to the roots resulted in the destruction of a certain proportion of the feeding rootlets, but when the injury was not extensive and the plant was vigorous, the treatment appeared to cause only a temporary retardation in the growth.

The application of carbon disulphide to soil before planting has been found to exert a stimulating effect on plants (*36, 45, 74, 138*), increasing the yields of field crops such as oats (*36, 60*), wheat (*60*), clover (*36, 60*), beans (*60*), beets (*60*), alfalfa (*60*), and potatoes (*60*), but it did not modify the yield of corn (*36*). Egorow (*20*) obtained increased shoot growth of pumpkin vines when they were put in jars of water containing carbon disulphide. Henry (*60*) and Vermorel (*153*), in 1901, and investigators at the Japanese beetle laboratory in more recent years, have found that many varieties of evergreen,

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deciduous, and herbaceous plants have grown in a satisfactory manner in soil that had previously been treated with carbon disulphide.

Although it has been possible in many cases to use carbon disulphide in the soil to destroy the Japanese beetle without causing serious damage to many varieties of plants, by maintaining the concentration and the exposure below that at which extensive injury is produced, the fact must not be overlooked that carbon disulphide is poisonous to plants. In view of this characteristic of the chemical, which, however, is not so marked as with certain other chemicals, it is necessary that it be used in the manner to be later specified.

EXPERIMENTS IN THE PRACTICAL USE OF CARBON DISULPHIDE AS A SOIL FUMIGANT FOR NURSERY STOCK

According to the quarantine requirements, greenhouse and nursery establishments within the infested area may have plants with soil about their roots certified for shipment to uninfested territory, provided no living stages of the Japanese beetle are present. Experiments were conducted to determine whether injections of carbon disulphide could be used to destroy the immature stages of the beetles in soil to be used subsequently for potting plants, heeling-in and plunging beds, and evergreen nursery stock in the field.

INJECTION OF CARBON DISULPHIDE INTO POTTING SOIL

CONCENTRATION AND PERIOD OF EXPOSURE NECESSARY TO DESTROY IMMATURE STAGES

Experiments were conducted to determine the quantity of carbon disulphide to be injected into loose soil in tight, metal-lined boxes ranging in volume from 8 to 50 cubic feet, and the period of exposure required to kill the immature stages of the beetle. Most of the experiments were made with third-instar larvae because this stage is present during the greater part of the year. Larvae and eggs were placed in special wire cages with soil and set in various positions during the process of putting soil into the boxes. After the carbon disulphide had been applied, the cover of the box was clamped tightly in place and left undisturbed for the period of treatment.

The preliminary experiments were made at a temperature of 55° F. in loosely packed, moist, clay loam. Dosages ranging from 60 to 240 g (0.132 to 0.528 pound) of carbon disulphide to a cubic yard were injected and left for a period of 48 hours. The effectiveness of these different quantities in killing third-instar larvae scattered throughout a cubic yard of soil is given in figure 15. It was found that at a temperature of 55° a dosage of 240 g of carbon disulphide to a cubic yard was the minimum quantity required to destroy the larvae within a period of 48 hours. This treatment was also applied for periods of 24, 48, and 72 hours at temperatures of 45° and 65°. It was found that a dosage of 240 g to a cubic yard was effective within a period of 24 hours at a temperature of 65°, but the exposure had to be prolonged for 72 hours to kill all of the larvae at a temperature of 45°, as is shown in figure 16. It was necessary to increase the dosage of carbon disulphide injected into a cubic yard of soil from 240 to 453 g (from 0.528 to 1 pound) to destroy the eggs, the most resistant stage, in the soil under these conditions.

In view of the fact that a concentration of 50 mg per liter was sufficient to kill larvae when removed from soil and exposed to the vapor

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for 48 hours at a temperature of 50° F., as shown in figure 5, *B*, and that when the larvae were in soil in the fumigation boxes, a dosage equivalent to 314 mg per liter was required to kill at a temperature of 55° within the same period of time, it is apparent that the factors of absorption and diffusion in soil influence appreciably the minimum quantity effective in destroying the larvae.

DIFFUSION OF CARBON DISULPHIDE VAPOR IN SOIL

It is customary in entomological work to trace the diffusion of an insecticidal vapor by determining the effect on insects placed at different distances from the point of injection. These biological indicators show the spread of a lethal concentration, but give no indication of the relative concentration of the vapor at the different positions. It was desirable, in studying the diffusion of carbon disulphide in soil in a fumigation box, to know the concentration of the vapor at different intervals during the treatment.

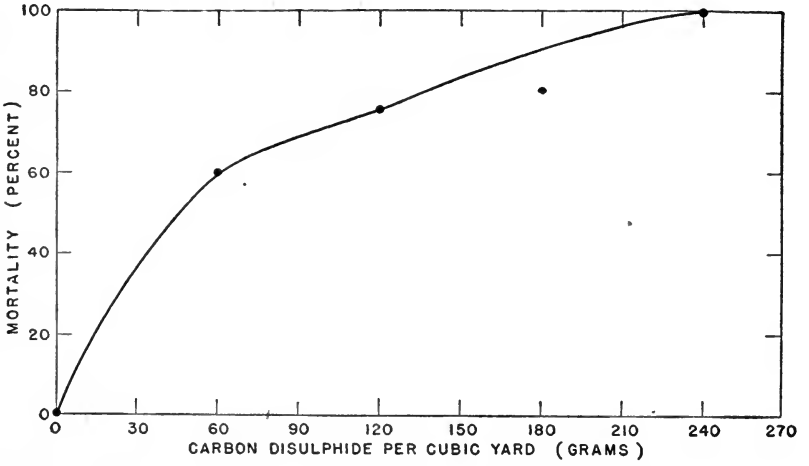

FIGURE 15.—Mortality of larvae of the Japanese beetle in soil due to exposure to different concentrations of carbon disulphide vapor in a gas-tight box for 48 hours at 55° F.

The concentration of the vapor in the soil was determined by withdrawing small samples of air from the different positions and analyzing them for carbon disulphide. It was realized that this method of measuring diffusion is open to serious objection in that the manner of obtaining samples tended to disturb the normal diffusion of the vapor in the soil. An attempt was made to overcome this objection by placing small vials containing soft cotton cord impregnated with sodium alcoholate at the different positions in the soil, as described by Rogers and Hatfield (*117*), but since no definite correlation was obtained between the quantity of carbon disulphide absorbed by this chemical indicator and the insect mortality, it was concluded that the procedure was not sufficiently accurate for this purpose. There appeared to be a direct correlation between the concentration of carbon disulphide in the air withdrawn from the soil and the mortality of the larvae.

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A study was made of the diffusion of carbon disulphide vapor in moist sandy loam in the fumigation box at a temperature of 55° F. While the soil was being put into the box, larvae in cages were placed at depths that would be 2, 6, 12, 18, and 24 inches below its surface and at distances of 5, 10, and 15 inches horizontally from the point of injection. Glass tubes were extended to these positions for withdrawing samples of air at intervals for analysis. Carbon disulphide at the rate of 240 g to a cubic yard was injected into the soil to a depth of 6 inches through a hole in the cover of the fumigation box. Samples of air were withdrawn for analysis 3 hours after the injection of the chemical and at various intervals up to 48 hours. At the end of the experiment, the larvae were removed and examined to determine the effect of the treatment.

From the data in figure 5, *B*, where a concentration of 90 mg per liter killed larvae in 24 hours and 200 mg in 12 hours at a temperature

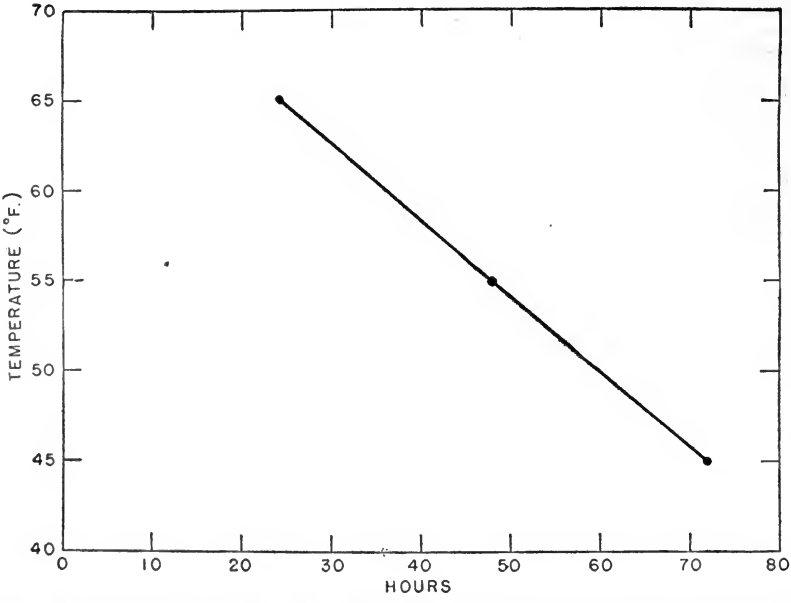

FIGURE 16.—The minimum exposures at different temperatures required to kill larvae of the Japanese beetle when exposed to the vapor from 240 g of carbon disulphide in a cubic yard of soil.

of 50° F., it was considered at the end of 24 hours that in all positions where the concentration had been 90 mg or more for 24 hours, or 200 mg or more for 12 hours, the larvae would be dead. The final examination at the end of 48 hours showed that the larvae were dead in all such positions.

When carbon disulphide is injected into soil as a liquid, it begins to volatilize and saturates the air in immediate contact with it. The vapor does not diffuse uniformly in all directions, but tends to diffuse downward and laterally from the point of injection, forming, in general, a cone-shaped region whose apex is close to the point of application. At the end of 24 hours in the present experiments the insecticidal area extended within a horizontal radius of 5 inches of the injection hole to a depth of 12 inches below the surface, and within a horizontal radius

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of 10 inches of the vertical projection of the point of injection at depths of 18 and 24 inches below the surface. At the end of 48 hours the carbon disulphide had diffused in insecticidal concentration within a horizontal radius of 15 inches from the injection hole to a depth of 24 inches. The results of the foregoing experiments are presented graphically in figure 17. The lines drawn from the point of injection to the various positions indicate that the larvae were dead at those positions; where no line is drawn to a given point all the larvae at that point were not killed.

In wet soils, slightly permeable, the carbon disulphide treatment was not satisfactory because the vapor did not diffuse in insecticidal concentration even on exposures up to 96 hours. In this case water inhibited the volatilization of the chemical and filled the air spaces in the soil to such an extent as to prevent dispersion of the vapor. It is apparent that the successful treatment of potting soil with carbon disulphide is limited to permeable soils through which the vapor can diffuse.

In general, the consistency of the soil and its physical condition at the time of treatment influence in a very important degree the diffusion of an insecticidal concentration of the vapor. The diffusion is most rapid in permeable soils and takes place slowly in compact soils. Excess water in the soil prevents the dispersion of the vapor. Lumpy soil is not satisfactory for treatment because the vapor may not penetrate into the lumps. Satisfactory results can be obtained only when the soil is in a proper physical condition for treatment.

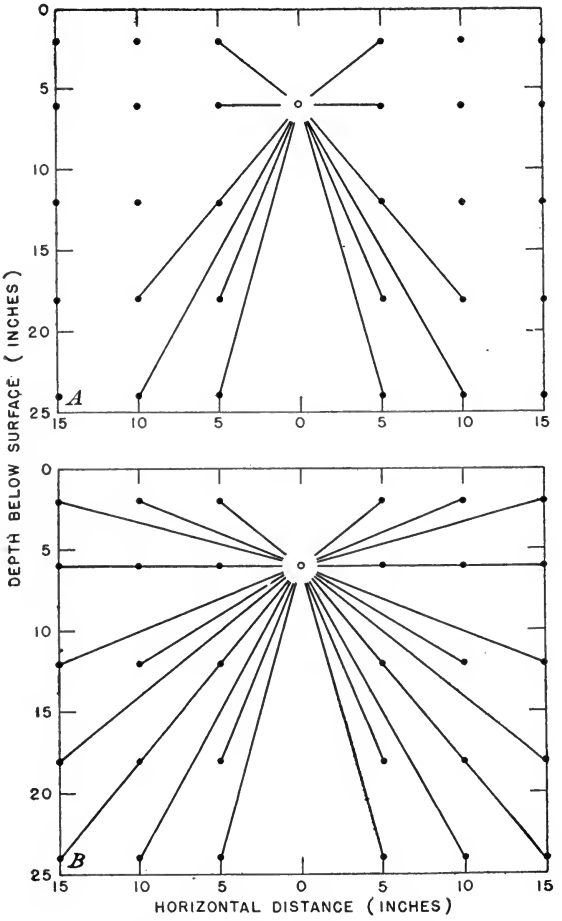

FIGURE 17.—Diffusion of carbon disulphide in insecticidal concentration in soil in the fumigation box at a temperature of 55° F. when injected at the rate of 240 g to a cubic yard to a depth of 6 inches: *A*, After 24 hours; *B*, after 48 hours.

ARRANGEMENT OF INJECTION HOLES

The results in the study of the diffusion of carbon disulphide in soil indicate that the maximum horizontal diffusion of an insecticidal

concentration of the vapor at a temperature of 55° F. within a period of 48 hours is 15 inches. Larvae were killed near the surface and at a depth of 18 inches below the point of injection. If the injection holes are arranged in such a manner that the maximum distance an insecticidal concentration has to diffuse horizontally from the point of injection to kill an egg or larva is only 12 inches and the maximum depth from this point is only 16 inches, it is apparent that the permeation of an insecticidal concentration to all parts of the soil can be assured.

The carbon disulphide may be applied in any fumigating box while the box is being filled with soil. After 18 inches of soil has been placed in the box, the liquid carbon disulphide may be distributed in holes 2 inches deep and 18 inches apart, each hole being filled with soil immediately after each portion of the liquid has been applied. When used at the rate of 453 g (1 pound) to a cubic yard, each position should receive 55 g (approximately 1½ fluid ounces) of the liquid. After the first 18 inches of soil has been treated, additional 18-inch layers of soil can be placed in the box and treated in the same manner until the box is filled with treated soil. Or, the box may be filled with soil and the chemical poured into deep holes through a tube to insure that it reaches the same points.

ABSORPTION OF VAPOR BY SOIL, PEAT, AND MANURE

It is generally recognized that the absorption of a vapor by soil is governed by the relative size and composition of the particles. The finer particles are more absorptive than the larger particles. The organic constituents of the soil are among the most highly absorptive. It is probable that the portion of insecticidal vapor absorbed by the soil particles is no longer effective in killing insects.

A study was made of the absorptive power of different soils, peat, and decomposed manure for carbon disulphide vapor. Carbon disulphide was injected into approximately 1 cubic foot of each of these materials at the rate of 1 g to a liter of space. The container was then sealed and left for 48 hours. The unabsorbed carbon disulphide vapor was then withdrawn from the container by passing a stream of air through the soil until no traces of carbon disulphide could be detected in the air leaving it. The quantity of carbon disulphide per liter thus recovered from each material was as follows:

	Milligrams
Peat moss	100
Decomposed manure	100
Clay	200
Clay loam	280
Sandy loam	600
Sand	800

It is apparent that the persistence of the vapor in the soil air is affected by the absorptive power of the soil particles. In view of the fact that carbon disulphide injected at the rate of 453 g (1 pound) to a cubic yard has killed all stages of the Japanese beetle in these soils, manure, and peat moss, the absorption of the vapor by the particles of these materials apparently is not sufficient to reduce the concentration in the soil air to a point where the treatment is not effective.

The quantity of carbon disulphide vapor removed from the soil air by the particles of soil is also influenced by the temperature and the number of times the chemical has been applied previously to the soil. Two samples of clay loam were treated with carbon disulphide in the

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manner described above. One was kept at a temperature of 60° and the other at 80° F. for a period of 48 hours. It was possible to recover only 28 percent of the chemical from the soil maintained at 60°, while 49 percent was recovered from the air in the soil at 80°.

When all the carbon disulphide had been removed from the soil air in the sample maintained at 60° F., the treatment was repeated and the soil left indisturbed for a second 48-hour period. It was possible to recover 84 percent of the second application of the chemical from the soil air. In the third and fourth re-treatments, practically all of the carbon disulphide applied was recovered from the soil air. This indicates that the absorptive power of the soil for carbon disulphide vapor decreased with repeated applications of the chemical, leaving a larger proportion of each successive application available in the soil air.

EFFECT OF FUMIGATION ON THE SUBSEQUENT GROWTH OF PLANTS

In a preliminary experiment by the senior author (*26*) common bean (*Phaseolus vulgaris*), the common pea (*Pisum sativum*), and common nasturtium (*Tropaeolum majus*) were sown in soil that had been treated with carbon disulphide at rates ranging from 1 to 80 pounds to the cubic yard. It was found that the fumigation generally stimulated the growth of these plants, the increase in the weight and in the height of the plants being in general directly proportional to the quantity of carbon disulphide applied to the soil. When used at the rate of 1 pound to the cubic yard, the quantity required to destroy all immature stages of the Japanese beetle, the chemical appeared to have little effect on the growth of these plants.

Several groups of nursery and greenhouse plants were then planted in soil that had been fumigated with carbon disulphide in the proportion of 1 pound to the cubic yard and in untreated soil to determine the effect of the treatment on the subsequent development of the plants. The Persian cyclamen (*Cyclamen persicum*) seemed to be slightly retarded by the treatment, but the other plants developed normally and in some cases were stimulated. Among the greenhouse plants which appeared to grow satisfactorily in the fumigated soil were maidenhair fern (*Adiantum* sp.), centuryplant (*Agave americana*), common aspidistra (*Aspidistra lurida*), amoena azalea (*Azalea amoena*), Hinodegiri azalea (*A. hinodegiri*), Indica azalea (*A. indica*), spotted begonia (*Begonia maculata*), Mexican cibotium (*Cibotium schiedei*), Pindo palm (*Cocos australis*), horticultural varieties of croton (*Codiaeum variegatum*), Scotch heather (*Calluna vulgaris*), house hollyfern (*Cyrtomium falcatum*), dracena (*Dracaena* sp.), India rubbertree (*Ficus elastica*), English ivy (*Hedera helix*), house hydrangea (*Hydrangea opuloides*), Sander Kentia (*Kentia sanderiana*), common screwpine (*Pandanus utilis*), polypody (*Polypodium* sp.), poinsettia (*Poinsettia pulcherrima*), and bowstring-hemp (*Sansevieria zeylanica*). The following nursery plants appeared to grow normally in fumigated soil: White fir (*Abies concolor*), common box (*Buxus sempervirens*), Sawara retinospora (*Chamaecyparis pisifera*), rock cotoneaster (*Cotoneaster horizontalis*), Norway spruce (*Picea excelsa*), Douglas fir (*Pseudotsuga douglasi*), common red oak (*Quercus rubra*), rose (*Rosa* sp.), common lilac (*Syringa vulgaris*), American arborvitae (*Thuja occidentalis*), and oriental arborvitae (*T. orientalis*).

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This treatment has been applied by several of the large nursery and greenhouse establishments within the quarantined area since 1924 and used in growing all varieties of plants with apparent success. Fumigation with carbon disulphide seems to have an added advantage to the grower in that it is claimed that the vapor kills certain weed seeds in the soil. It was estimated in 1931 that 80 commercial establishments grew plants satisfactorily in soil that had been fumigated with carbon disulphide to destroy the immature stages of the Japanese beetle.

INJECTION OF CARBON DISULPHIDE INTO HEELING-IN GROUND AND PLUNGING BEDS

When it was demonstrated that soil used for potting purposes could be fumigated successfully, the eradication of the larvae from plunging beds, heeling-in grounds, and coldframes in the commercial nurseries was undertaken. A study was made of the diffusion of different

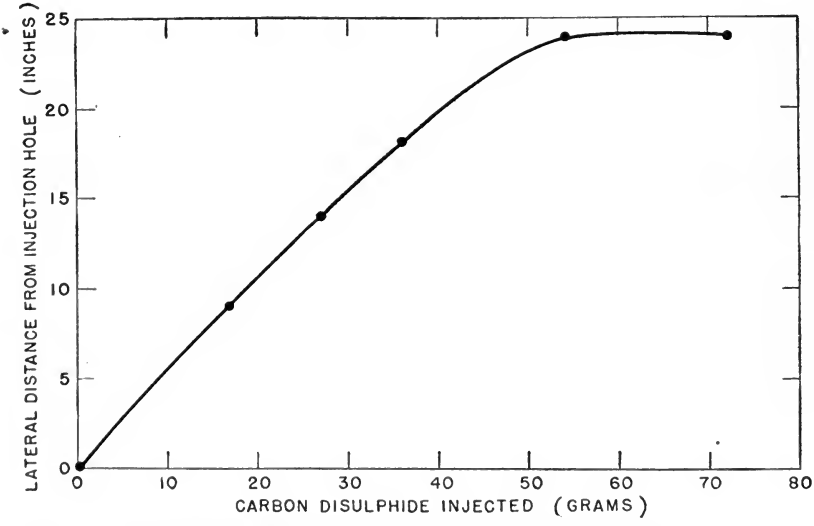

FIGURE 18.—Lateral diffusion of carbon disulphide vapor in concentrations lethal to the larvae of the Japanese beetle. Determined in moist clay loam in situ at 45° to 62° F.

dosages of carbon disulphide in moist clay loam in situ at temperatures ranging from 45° to 62° F. in the upper 3 inches to determine the effective range of each dosage. Larvae in cages with soil were placed in the ground to a depth of 2 inches at distances ranging from 3 to 30 inches from the point where the chemical was to be injected. A dose of carbon disulphide was then injected to a depth of 2 inches. The treated area was covered with a tarpaulin and left undisturbed for 48 hours. The larvae were then removed from the cages to determine the effect of the treatment. The results of this experiment are given in figure 18.

The maximum effective lateral diffusion of the vapor from an injection hole was 24 inches. This effective range, which was obtained with a dose of 54 g, was not increased by increasing the dose to 72 g. As it was found in the experiments with potting soil that the larvae near the surface of the soil are more difficult to kill by this method than those

6 inches or more below the surface because of the loss of the vapor to the atmosphere and the tendency of the chemical to diffuse downward in the soil, it is apparent that when larvae within 2 inches of the surface are killed by a treatment, the death of those at depths up to 18 inches in a permeable soil can be assured. During the growing season the larvae are usually found within the upper 6 inches of soil, although occasionally some of them may be found at a depth of 12 inches below the surface. In general, all larvae can be destroyed by impregnating the soil to a depth of 12 inches with an insecticidal concentration of carbon disulphide vapor.

The physical condition of the soil has an important influence on the effectiveness of the treatment. The effective insecticidal action of the vapor is usually completed within 48 hours after injection of the chemical; therefore, the soil must be in suitable condition to assure the proper diffusion of the vapor in a short time. Rocky soils are not

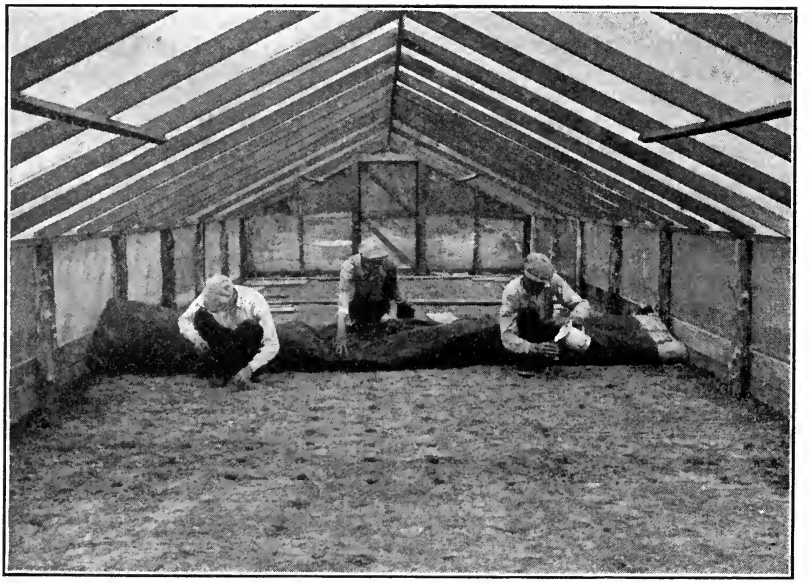

FIGURE 19.—Method of applying measured doses of carbon disulphide in a screened bed, the ground being covered by a tarpaulin as the men applying the insecticide move forward.

of uniform texture, and the diffusion of the vapor is irregular. Heavy clay soils, when dry, are usually broken by cracks and crevices and may be lumpy, thus permitting the vapor to escape to the atmosphere. The degree of moisture in the soil at the time of treatment is an important factor in securing the proper diffusion of carbon disulphide. The vapor does not diffuse through wet soils. The diffusion appears to be best in soils that are only partially saturated with water.

In the experimental treatments the doses of carbon disulphide were measured in a graduated cylinder and poured into the holes, as shown in figure 19. In the application of the chemical in commercial nurseries it would be advantageous to use an injector which can be regulated to deliver the required quantity of chemical at each injection. In some special cases where nursery beds are equipped with tile pipes in the soil for steam sterilization, the necessary quantity of carbon

disulphide may be volatilized and distributed through the soil by means of this system, as described by Riley (*115*).

It is possible to arrange the series of injections in a plot in such a manner that the limits of the killing zones around the holes overlap and produce an insecticidal atmosphere throughout the soil. A more uniform diffusion is probably obtained by distributing the carbon disulphide in small doses in a large number of holes than is obtained by dividing an equal quantity among a few holes. It is advisable, however, to reduce the manual labor to a minimum. It is suggested that the chemical be injected to a depth of 2 inches in holes spaced 12 inches apart. In such case, 27 g (three-fourths of a fluid ounce) should be placed in each hole. This treatment has been applied successfully since 1924 on plunging beds, on heeling-in ground, and in coldframes in commercial nurseries, except when the soil was excessively wet and in poor physical condition, or when the temperature was below 45° F.

INJECTION OF CARBON DISULPHIDE INTO SOIL OF POTTED PLANTS

A series of experiments was begun in 1922 to determine whether the larvae of the Japanese beetle could be destroyed by injecting carbon disulphide into the soil of potted plants without damaging the plants. A group of Hinodegiri azaleas growing in 6-inch pots, and a group of Mexican cibotiums growing in 8-inch pots were infested by loosening the soil at the surface of each pot and placing 5 active third-instar larvae on the surface, covering them with soil, and leaving them undisturbed for 1 week to establish themselves in their new environment.

A hole was made with a slender steel instrument to the approximate center of each mass of soil, and then the chemical was injected by means of a Mohr pipette at rates of 0.5, 1, 2, 5, and 10 g per pot. The holes were immediately filled with soil, and the plants were placed in a commercial greenhouse, where they were kept at a temperature of 60° F. and supplied with water as required. At the end of 2 weeks a record was made of the appearance of each plant, and the larvae were removed from the soil to determine the effects of the treatment. It was found that the larvae in the vicinity of the injection holes were killed, but that those near the surface of the soil or in contact with the clay pot sometimes escaped, even when a dose of 10 g was injected. The injection of 2.5 g of carbon disulphide about the roots seriously injured these plants.

In an effort to overcome the injurious effect of the chemical on the plants, gelatine capsules containing 1.5 g of carbon disulphide were placed in holes about the roots of potted azaleas and covered with soil. It was expected that under the action of the soil moisture and the soil organisms the gelatin would dissolve and liberate the carbon disulphide slowly. It was found that the disintegration of the gelatin capsules was irregular and prolonged over a period of several weeks. The application of the chemical in this manner did not destroy the larvae in the potted plants.

Gardner (*40*) reported that injections of small doses of carbon disulphide at intervals was successful in eradicating mealybugs (*Pseudococcus* sp.) from the soil of boxed and potted plants. It was found that the larvae of the Japanese beetle also could be destroyed by this pro-

cedure without serious damage to Hinodegiri azaleas in 6-inch pots by injecting 1.5 g of the chemical into the soil at intervals of 48 hours until 4.5 g had been applied. The treatment was successful in pots containing moist, permeable soil, but was not always successful in pots containing wet soil. The treatment, however, was not viewed with favor because of the manual labor involved, the limiting factor of soil moisture, and the possible hazard to the plants in commercial nurseries.

INJECTION OF CARBON DISULPHIDE INTO SOIL ABOUT THE ROOTS OF EVERGREEN NURSERY STOCK

Vermorel (*153*) reported that Danvesse, in 1881, had used injections of carbon disulphide at the rate of 120 g per square meter and destroyed the grub of *Melolontha vulgaris* in beds of *Abies* sp., *Betula* sp., *Carpinus* sp., *Chamaecyparis* sp., *Fagus* sp., *Larix* sp., *Picea* sp., *Pinus* spp., *Pseudotsuga* sp., *Rosa* spp., and *Thuja* spp. without causing injury to plants 1 to 3 years old. Vermorel, himself, claimed that such a dosage was injurious to growing plants and that 30 g, which was not harmful to the plants, was all that was necessary, in most cases, to control this insect. This method has been further investigated by Falconnet and Treyre, as reported by Bourcart (*8*), and by Rolet (*118*), Faes and Staehelin (*22*), and Köbelin (*75*), and it was found that when applied at the proper time, damage by larvae of *Melolontha vulgaris* was reduced to negligible proportions.

In the spring of 1924 a number of tests were made to determine whether the soil about the roots of 3-year-old Norway spruce, American arborvitae, and Canada hemlock could be treated without causing serious injury to the plants, by injecting carbon disulphide at the rate of 27 g (three-fourths of a fluid ounce) to a square foot. This was the minimum dose, as determined in the experiments in heeling-in ground and plunging beds in nurseries, that could be depended on to destroy larvae in the soil in the field.

Three weeks after treatment all the hemlock were dead, and some of the spruce and arborvitae showed signs of injury by the wilting of the growing tips. An examination of the treated plants showed that the roots within a radius of 4 inches from the point of injection were usually killed by the carbon disulphide, and that the rootlets were sometimes killed at greater distances. The treated plants not killed were checked in growth throughout the whole year. The results indicate that the roots of evergreen nursery stock are more readily killed by injections of carbon disulphide than are the larvae of the Japanese beetle, and that the treatment was too hazardous to use in commercial nurseries.

FUMIGATION OF SOIL ABOUT THE ROOTS OF BALLED AND POTTED NURSERY STOCK WHILE PROTECTING THE AERIAL PORTIONS

Many attempts to fumigate growing nursery plants with carbon disulphide vapor in a fumigation chamber for the purpose of killing larvae in the soil about the roots proved unsuccessful, because the aerial portions of the plants were severely injured before the vapor penetrated into the soil in sufficient concentration to kill the insects. In preliminary experiments in 1924 Leach and Fleming (*81*) showed that the aerial portions could be protected during fumigation by submersion in water. A diagram of one of the later tanks for fumi-

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gating soil about the roots of plants without subjecting the aerial portions to the gas is shown in figure 20. As no apparatus for vaporizing the carbon disulphide was used, complete destruction of the larvae was not obtained in less than 8 hours. The experiments were temporarily discontinued in the fall of 1925 because nurserymen operating large commercial nurseries stated that the use of a procedure requiring 8 hours of fumigation would disrupt too seriously the routine of preparing plants for shipment.

In 1928 it was found that when carbon disulphide was vaporized rapidly by means of a device similar to the "gasifier" described by Weigel, Young, and Swenson (*159*), and the maximum concentration of the vapor was obtained within a few minutes, the minimum exposure required to kill larvae in moist soil was reduced to 2 hours.

DISTRIBUTION OF CARBON DISULPHIDE IN THE FUMIGATION TANK

A study was made of distribution of carbon disulphide in a 6,300-l rectangular fumigation tank which was equipped with a "gasifier" for vaporizing the chemical, a coil for heating the air, fans for circulating

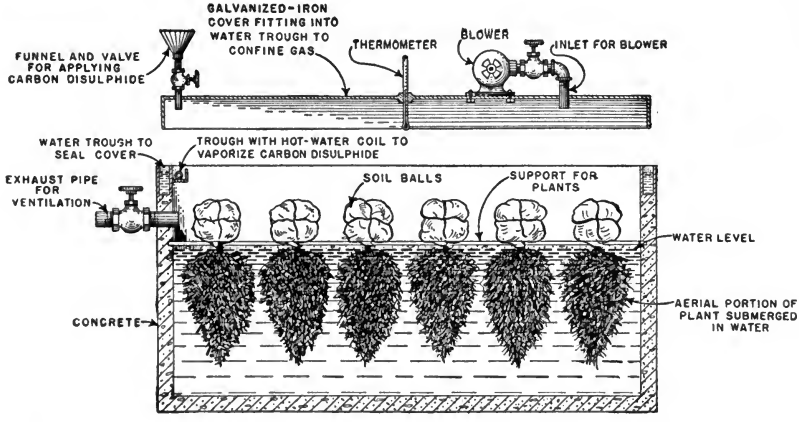

FIGURE 20.—Diagram of tank for fumigating soil about the roots of nursery plants without subjecting the aerial portions to the gas.

the air, a device for circulating and aerating the water without permitting the gas above the water to escape, a water seal for the cover, and the necessary valves and blower for forcing the gas out of the tank. The tank was filled to two-thirds of its volume with water.

Tests were made to determine the method of operating this tank whereby the vapor would be uniformly distributed through the air and the smallest quantity of the chemical absorbed by the water. Carbon disulphide was vaporized in the tank at the rate of 25 pounds to 1,000 cubic feet, with the air at a temperature of 90° F. and the water at a temperature of 60°. Two hours later samples of air were taken at points 5, 15, and 25 inches above the water, and samples of water were taken at 5, 15, 25, 35, 45, and 55 inches below the surface. The quantity of carbon disulphide in the samples was determined by titration with iodine according to the regular procedure. The distribution of the carbon disulphide in the tank was visualized by dividing the air and water into horizontal layers, each 10 inches

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deep, and estimating the average concentration of the chemical in each layer. Tests were made with the water and the air quiet, the water circulating and the air quiet, the water quiet and the air in motion above the water, and with the water circulating and the air in motion above the water. The distribution of carbon disulphide in the tank after 2 hours under each of these conditions is given in figure 21.

It was found that keeping the air in motion above the water distributed the vapor uniformly through the air but increased the quantity of carbon disulphide absorbed by the water. The aeration system obviously was inadequate properly to remove the gas from the water. Circulating the water tended to distribute the chemical uniformly to a depth of 60 inches below the surface. When the water and air were quiet in the tank the vapor was more concentrated in the layer of air in contact with the water than in the other layers, and the quantity of carbon disulphide absorbed by the water was relatively small and concentrated in the surface layer. It was apparent the best method of applying the treatment to plants was with the air and the water quiet in the tank.

RELATION BETWEEN CONCENTRATION OF VAPOR IN TANK AND THE MORTALITY OF LARVAE IN SOIL

It was expected that this procedure, if satisfactory, would be applied in the commercial nurseries between October and June when the insect was present in the soil in the larval stage. The experiments to determine the minimum quantity of carbon disulphide required under these conditions were made only with third-instar larvae.

A series of tests were made at temperatures ranging from 65° to 90° F. to determine the minimum quantity of carbon disulphide required to kill the larvae in 3-inch pots of moist soil within a period of 2 hours. A summary of the results obtained is given in figure 22. It was found that a concentration of approximately 8.5 pounds of carbon disulphide to 1,000 cubic feet was effective at a temperature of 90°. The quantity required increased progressively as the temperature was lowered until at 65° more than 20 pounds was necessary to destroy the larvae. As 80° appears to be the maximum temperature usually recommended for the fumigation of living plants, it was decided to conduct further tests at this temperature.

The depth to which the vapor must penetrate into the soil to kill an insect is often a limiting factor. A series of tests were made to determine the effectiveness of different dosages in destroying the larvae in moist sandy loam in 3-, 6-, 8-, and 12-inch earthen pots within a period of 2 hours at a temperature of 80° F. The minimum dosages necessary to destroy the larvae in different pots of soil are given in figure 23. It was found that the dosage of 15 pounds which was sufficient to kill in 3-inch pots had to be increased to 25 pounds to kill in 8-inch and in 12-inch pots. As the vapor penetrates more readily through balls of soil wrapped with burlap than through soil in earthen pots, it is obvious that a treatment which is effective in destroying larvae in pots can be depended upon to destroy them in balls of soil of the same volume.

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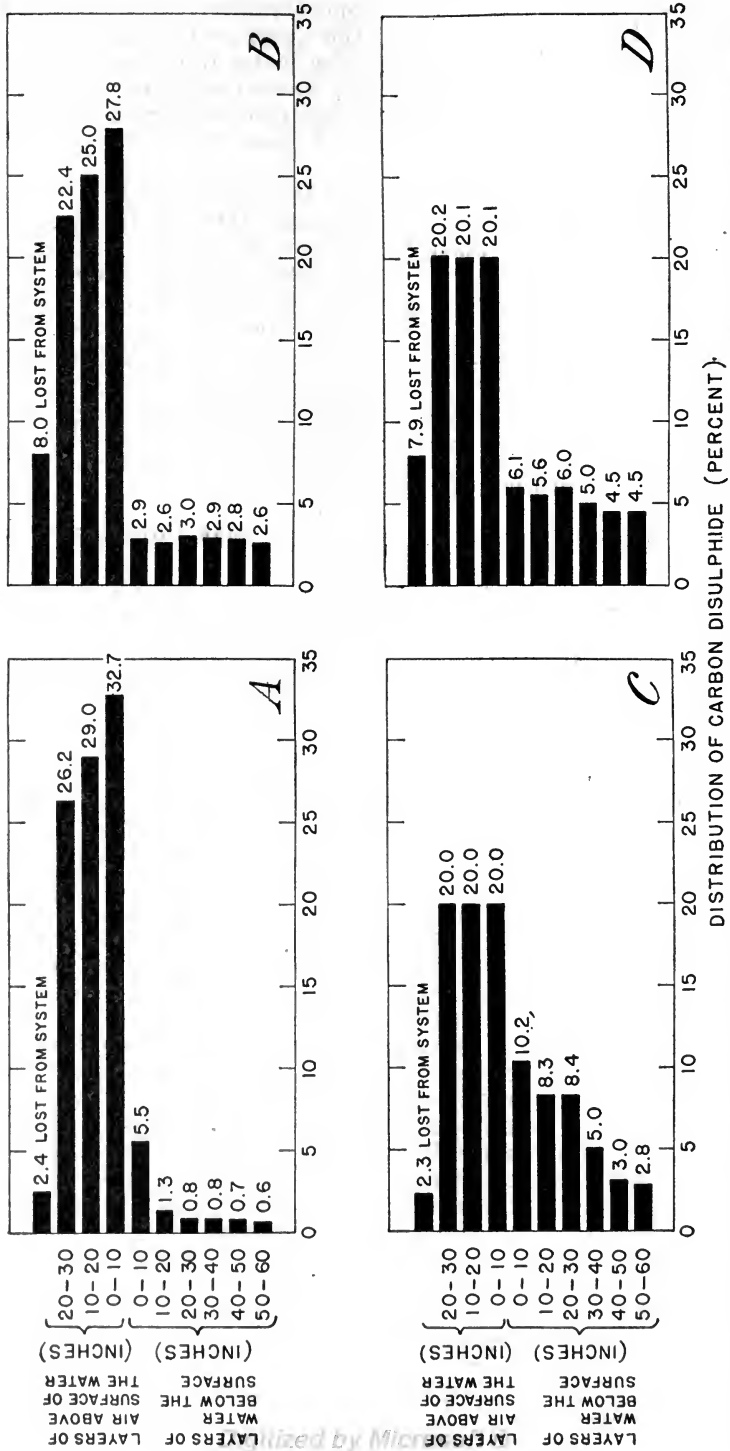

FIGURE 21.—Distribution of carbon disulphide in a fumigation tank after 2 hours. Dosage, 840 g; volume of air, 2,100 l; volume of water, 4,200 l; air temperature, 90° F.; water temperature, 60°: *A*, Air and water quiet; *B*, air quiet and water circulating and aerating; *C*, air in motion and water quiet; *D*, air in motion and water circulating and aerating.

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The moisture content of the soil at the time of treatment appears to be the greatest limiting factor. Pots of infested sandy loam, ranging in moisture content from half to completely saturated, were fumi-

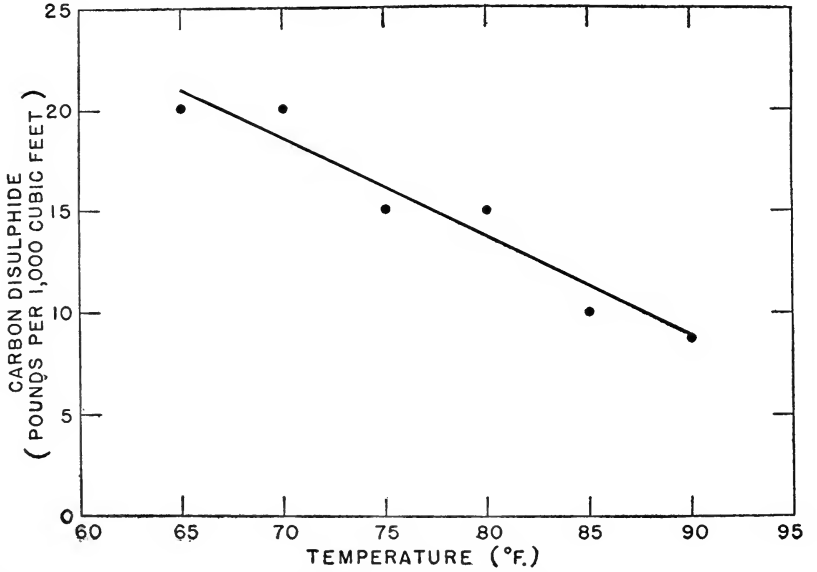

FIGURE 22.—Relation between temperature and the minimum concentration of carbon disulphide, rapidly vaporized, effective in destroying larvae of the Japanese beetle in 3-inch pots of moist sandy loam with an exposure of 2 hours.

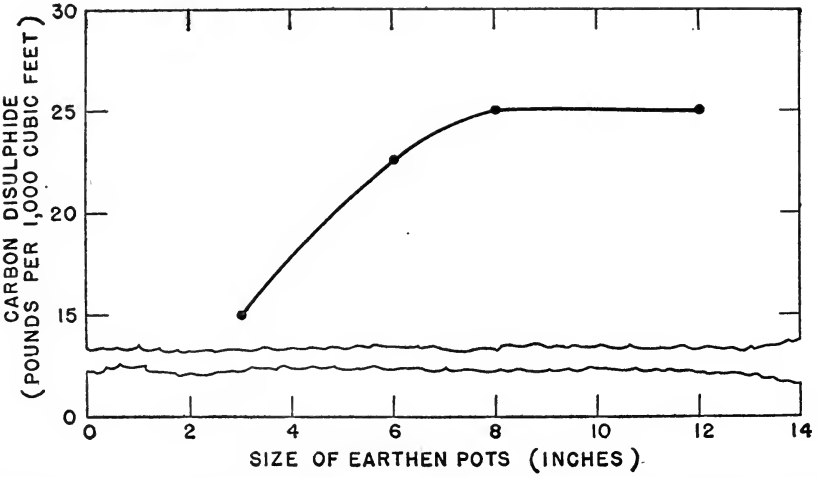

FIGURE 23.—Relation between the size of the earthen pot and the minimum concentration of carbon disulphide, rapidly vaporized, effective in destroying larvae of the Japanese beetle in moist sandy loam with an exposure of 2 hours at 80° F.

gated with dosages ranging from 15 to 30 pounds to 1,000 cubic feet for 2 hours at an air temperature of 80° F. It was found that when the soil was half saturated with water, the larvae were destroyed in

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8-inch pots by a dosage of 25 pounds. When the soil was three-quarters saturated with water an occasional larva survived, but when the soil was saturated with water, most of the larvae survived, even when dosages of 30 pounds to 1,000 cubic feet were used. It is apparent that the soil must be in condition for the proper penetration of the vapor in order for the treatment to destroy the larvae.

EFFECT OF FUMIGATING THE ROOTS OF AZALEAS AND HYDRANGEAS ON THE SUBSEQUENT DEVELOPMENT OF THE PLANTS

In the fall of 1930 hydrangeas, variety Mme. E. Chautard, growing in 6-inch pots and Indica azaleas, varieties Mme. Petrick and Mme. Van der Cruyssen, in 5-inch pots, were fumigated for 2 hours with the aerial portions submerged in water. The temperature of the air in the tank was 80° F. and that of the water was 60°. The dosages of carbon disulphide ranged from 10 to 45 pounds to 1,000 cubic feet. After treatment the plants were placed in the greenhouse and forced according to the usual commercial practice. A record was made at weekly intervals of the condition of the plants, and, as the plants

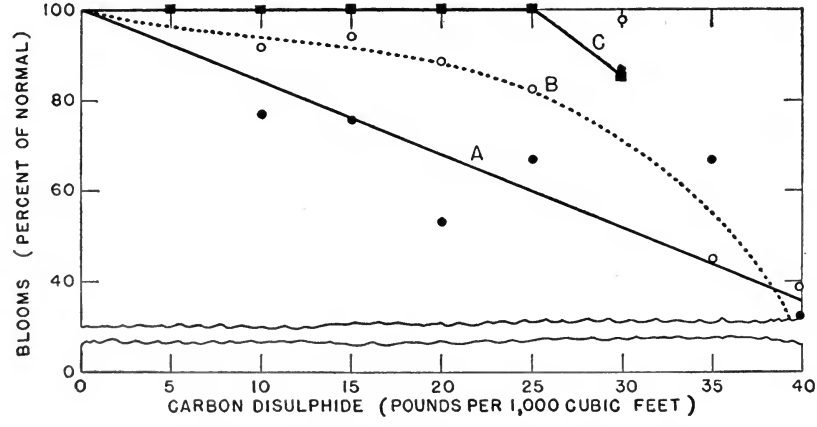

FIGURE 24.—Injury to azaleas and hydrangeas, as evidenced by the number of blooms as compared with the untreated plants, caused by fumigation of soil balls with carbon disulphide vapor in various concentrations. Period of fumigation, 2 hours; temperature of air, 80° F.; temperature of water, 60°; *A*, Mme. Van der Cruyssen azalea; *B*, Mme. Petrick azalea; *C*, Mme. E. Chautard hydrangea.

came into bloom, the quality and the number of blooms on each plant were noted.

In view of the fact that the commercial value of these plants is associated with their blooms, a careful survey was made of the blooms in each group. The quality of the blooms was not modified by the treatment but in some cases the number of blooms was appreciably reduced. The number of blooms in the treated groups of these plants as compared with the average number on the untreated plants is given in figure 24.

From a consideration of figure 23, it is apparent that a dosage of 20 pounds of carbon disulphide would be sufficient to destroy the larvae in the 5-inch pots of the azaleas. This dosage destroyed one-third of the blooms on the variety Mme. Van der Cruyssen and one-tenth of the blooms on the variety Mme. Petrick. It is doubtful whether this treatment could be used successfully on the Indica

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varieties of azaleas although the results with the variety Mme. Petrick indicate that some of them might withstand the action of the vapor. The hydrangea Mme. E. Chautard was not injured by a dosage of 25 pounds, which was sufficient to destroy the larvae in the 6-inch pots. The results indicate that potted hydrangeas might be treated successfully by this procedure. The reaction of these different plants to the treatment shows very definitely the necessity of testing the resistance of each variety in an experimental manner before attempting to apply the treatment on a commercial scale.

EXPERIMENTS IN THE USE OF EMULSIFIED CARBON DISULPHIDE AS A SOIL FUMIGANT FOR NURSERY STOCK

SUBMERGING SOIL ABOUT THE ROOTS OF PLANTS IN THE EMULSION

Submersion in an insecticidal concentration of carbon disulphide emulsion would appear to be, on superficial consideration, one of the simplest, most dependable and most economical methods for destroying infestations of the Japanese beetle in the soil of a potted plant or in the mass of soil about the roots of a plant that has been dug in the field. It is a relatively simple problem to kill the different stages of the insect after they have been removed from soil, involving only regulation of dosage, period of exposure, and temperature; but when the pests are embedded in soil about the roots of a plant, it is an intricate problem involving the additional complex factors of porosity of soil, absorption, and the susceptibility of the plant.

DISTRIBUTION AND LOSS OF CARBON DISULPHIDE FROM THE DILUTE EMULSION IN AN OPEN TANK

It was realized that in using carbon disulphide emulsion in an open tank there might be some stratification of the chemical because of its weight, a homogeneous mixture might not be obtained, and there would be some of the toxic agent lost by evaporation. Eight hundred gallons of a dilute emulsion, having a theoretical carbon disulphide content of 273 mg per liter, were prepared in a rectangular galvanized-iron tank, which was 10 feet square and 2 feet deep, the mixture being stirred gently until it was apparently homogeneous. Samples of dilute emulsion were taken from the bottom and from the surface at different positions in the tank, immediately after mixing and at intervals up to 48 hours, and analyzed to determine the concentration of carbon disulphide. A summary of these results is given in figure 25.

It was found that the emulsified carbon disulphide was not uniformly distributed through the water by the mixing operation, as the samples taken from different positions immediately after the mixing ranged from 250 to 375 mg per liter. There was no evidence of stratification throughout the period of 48 hours, but the carbon disulphide was gradually lost from the emulsion by evaporation, the concentration being decreased to an average of 112 mg per liter at the end of 48 hours.

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VOLUME OF EMULSION TAKEN UP BY SUBMERGED SOILS

When a mass of soil is submerged in an emulsion of carbon disulphide, the liquid flows into the soil and displaces the air to a large extent. The volume of emulsion penetrating into the soil is dependent upon the total volume of the interstitial spaces within the soil and upon the extent to which these spaces are already filled with water and roots. The volume of interstitial space in a soil is very small when the particles are cemented together in a compact homogeneous mass, but it is proportionally large when the soil is composed of numerous small particles, each of which preserves its own identity. In general the volume of the interstitial space in soil ranges from approximately 35 percent for sandy soils to 65 percent for clay soils, although, owing to cultivation and organic matter, a sandy loam might under certain conditions have an interstitial-space volume equivalent to that of clay loam.

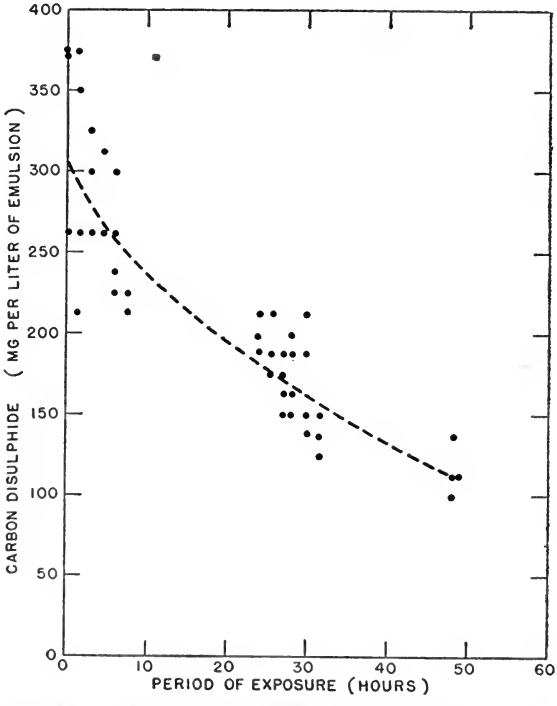

FIGURE 25.—Distribution of and loss of carbon disulphide from 800 gallons of dilute emulsion in an open tank at a temperature of 70° F.

The volume of emulsion taken up by the submerged soil may be modified to an appreciable extent by the development of roots in the interstitial spaces and around the outer side of the mass, as in a pot-grown plant. It was found (*30*) that there was a great difference in the quantity of liquid taken up by individual potted plants of the same variety and age, and growing under the same conditions. Small plants which were almost pot-bound took up as little as 0.2 g of liquid, whereas the plants with not so extensive root development absorbed as much as 37.3 g.

CONCENTRATION OF EMULSION IN INTERSTITIAL SPACES OF SUBMERGED SOILS

The carbon disulphide emulsion which penetrates into submerged soil is markedly affected by the particles of soil. It is an established fact that passing water through soil more or less completely removes dissolved as well as suspended matter. The effect of the soil particles on the concentration of carbon disulphide in the interstitial spaces of submerged soils was studied in the laboratory by submerging known volumes and weights of clay loam, sandy loam, and peat in tarred

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brass cylinders, in an emulsion containing 630 mg of carbon disulphide per liter and determining the volume of liquid taken up and the quantity of carbon disulphide in different portions of the soil at various intervals after submersion. The cylinders used in this study were similar to those employed in the laboratories of the Bureau of Chem-

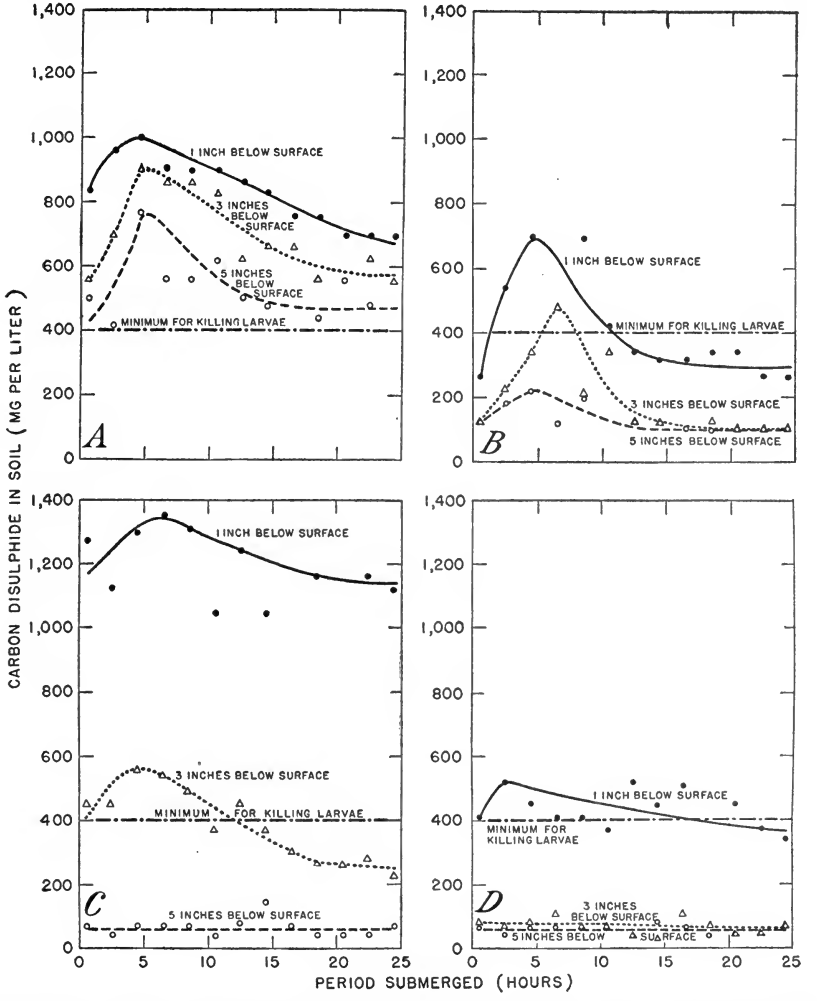

FIGURE 26.—Penetration of carbon disulphide emulsion into soil and peat in brass cylinders submerged for the periods indicated in emulsion at 70° F. Concentration of carbon disulphide in emulsion in tank, 630 mg per liter: *A*, Sandy loam, moist when submerged; *B*, sandy loam, wet when submerged; *C*, peat, moist when submerged; *D*, peat, wet when submerged.

istry and Soils for determining the water-holding capacity of soil (*164, p. 162*). The average quantity of carbon disulphide at points 1, 3, and 5 inches below the surface was expressed as milligrams per liter of emulsion. The results obtained with moist and wet sandy loam, and with moist and wet peat, the least and the most absorptive of these soils, are presented graphically in figure 26.

Most of the carbon disulphide was carried into the submerged soil when the emulsion flowed into the soil to replace the air in the interstitial spaces, although the gradual increase in the concentration for a period of 4 to 6 hours after submersion indicated that some of the chemical was diffusing into the soil from the surrounding emulsion. When the interstitial spaces in the soil are practically filled with water before submersion in the emulsion, the penetration of the emulsion into the soil is greatly inhibited.

As the emulsion passed into the soil, the particles of soil tended to remove the carbon disulphide, resulting in a concentration in the surface layer which was often in excess of that of the emulsion in the tank. With moist sandy loam, the concentration in the surface layer was approximately 50 percent in excess of that of the surrounding emulsion, but with moist peat the concentration in the surface layer was approximately 100 percent in excess. The average concentration of carbon disulphide at points 3 and 5 inches below the surface was dependent upon the volume of emulsion flowing into the soil and the quantity removed in the surface layer. With the highly absorptive peat, it appears that only a relatively small proportion of the chemical would penetrate to a depth greater than 3 inches.

After the maximum concentration of carbon disulphide at a given point in the soil had been reached in a period 4 to 6 hours after submersion, there was a progressive decrease in the concentration, which may be attributed to a physical or chemical union of the chemical with the soil particles in such a manner that the carbon disulphide is not liberated by aeration during the process of analysis. It is believed that the portion of the chemical that is so tightly bound to the soil particles as not to be removed at a temperature of 100° C. (212° F.) is no longer available as an insecticide.

It was determined (fig. 10) that third-instar larvae were killed, when removed from soil, by submersion in an emulsion containing 400 mg of carbon disulphide per liter for a period of 12 hours at a temperature of 70° F. This concentration is indicated in figure 26 as the theoretical minimum required to kill the larvae in the soil. When the concentrations of carbon disulphide at depths of 1, 3, and 5 inches below the surface are compared with this theoretical minimum concentration, it is apparent that one would expect complete mortality in the moist sandy loam to a depth of 5 inches, but only to a depth of 1 inch when this soil was wet at the time of submersion. With peat, one would expect complete destruction of larvae only to a depth of 3 inches when moist and to a depth of 1 inch when wet.

INSECTICIDAL ACTION IN SUBMERGED SOILS

The insecticidal action of carbon disulphide emulsion was studied by submerging masses of infested soil of known volume in different concentrations of the emulsion and determining the effect of the treatment on third-instar larvae. In the preliminary experiments, larvae in roughly spherical masses of loose moist sandy loam, approximately 3 inches in diameter, wrapped in moist, washed muslin, were submerged in emulsions ranging in concentration from 0.125 to 1.70 g of carbon disulphide per liter and maintained at a temperature of 70° F. At intervals up to 24 hours, masses of soil were removed from each emulsion and set aside to drain. When the soil was sufficiently dry,

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the larvae were removed and placed in untreated soil for observation. The results obtained by submerging the soil for periods of 6, 12, and 24 hours are presented graphically in figure 27.

The curves tend to approach the 100-percent line asymptotically, and it is accordingly difficult to determine exactly the minimum concentration of emulsified carbon disulphide required to penetrate into the soil and kill the larvae. The results indicate that periods of submersion of less than 12 hours are insufficient to destroy the larvae with these dosages; a period of 12 hours killed practically all of the larvae with a concentration of 1.7 g per liter. The results indicate, however, that a roughly spherical mass of loose, moist soil approximately 3 inches in diameter would have to be submerged for 24 hours in an emulsion containing 1.1 g of carbon disulphide per liter in order to assure the destruction of all larvae.

Another experiment was conducted to determine the effectiveness of the emulsion in killing larvae in loose sandy loam in muslin bags and

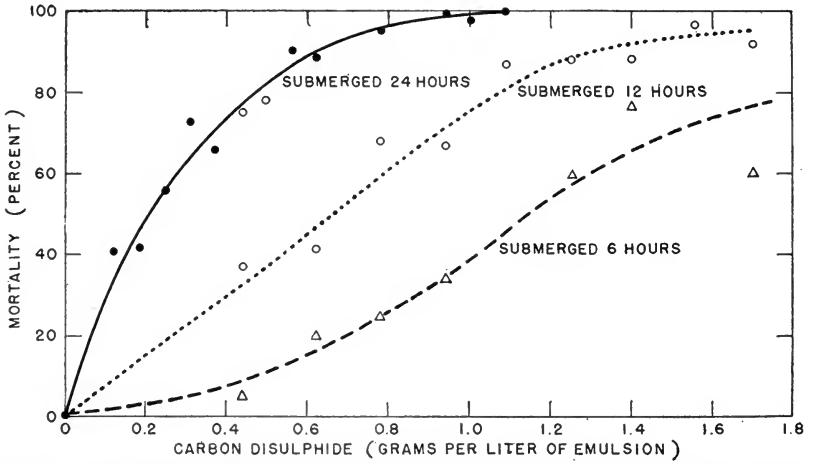

FIGURE 27.—Effectiveness of carbon disulphide emulsion in killing the larvae of the Japanese beetle contained in balls of soil submerged in emulsion. Moist sandy loam; volume of soil, 14 cubic inches; temperature, 70° F.

in pots of soil in which plants were growing. The volume of the soil in the muslin bags and in the pots was approximately 14 cubic inches. The bags of soil and the potted plants were infested with third-instar larvae and submerged in different concentrations of the emulsion, ranging in concentration from 0.125 to 1.7 g of carbon disulphide per liter, for 24 hours at a temperature of 70° F. After the treatment was completed the soil in the bags and in the pots was left undisturbed for a period of 2 weeks before determining the effect on the larvae. The results of this experiment are given in figure 28.

Submerging the pots in an emulsion containing 0.625 g of carbon disulphide per liter for a period of 24 hours killed all the larvae; a concentration of 1.0 g per liter was not effective in killing all of the larvae in the loose soil in bags. It is apparent that the penetration of carbon disulphide emulsion is better in soil where the granular structure of the particles of soil is not destroyed.

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A rapidly increasing concentration of carbon disulphide in the emulsion was necessary to penetrate into masses of submerged soil and destroy larvae with slight increments in the distance the larvae were below the surface. It was found that unless strong doses of carbon disulphide were used, the treatment generally was not completely effective when the larvae were more than 3 inches below the surface.

Possibly one of the most important limiting factors in the procedure is the extent to which the soil is saturated with water before submersion in the emulsion. In the tests, the insecticidal action was inversely proportional to the moisture content of the soil. The treatment was consistently effective only when the soil was less than half saturated with water.

It became apparent during the course of these experiments that the concentration of carbon disulphide in the interstitial spaces of a soil that is submerged in a dilute emulsion of the chemical is a complex

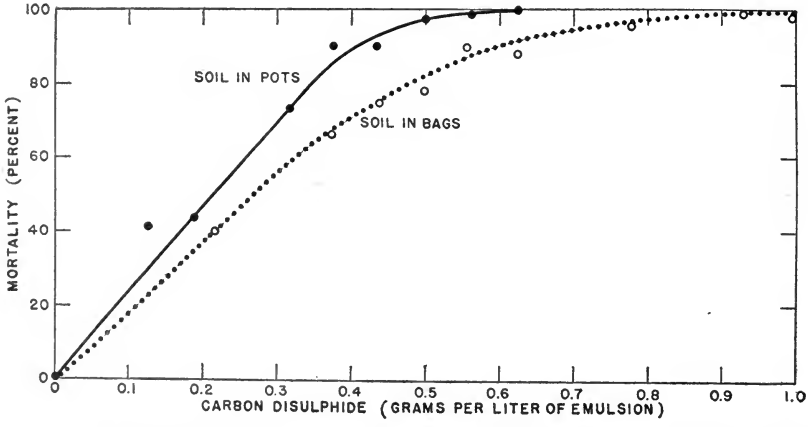

FIGURE 28.—Effectiveness of carbon disulphide emulsion in killing larvae of the Japanese beetle contained in loose bags of soil approximately 3 inches in diameter and in established soil in 3-inch pots submerged in the emulsion. Moist sandy loam; volume of soil in bags and in pots, 14 cubic inches; temperature, 70° F.; period of treatment, 24 hours.

resultant of many factors which are largely beyond control. In view of the heterogeneous mixtures of soils used in the commercial nurseries and the variation in volume, compactness, moisture, and organic matter, it is practically impossible to indicate any concentration of carbon disulphide emulsion that can be used generally for the destruction of larvae by this procedure.

EFFECT ON PLANTS WHEN ROOTS ARE SUBMERGED IN CARBON DISULPHIDE EMULSION

Experiments were carried on with several herbaceous perennials, deciduous shrubs, and evergreens to determine whether the roots of these plants could be submerged in a dilute emulsion of carbon disulphide for several hours without causing serious damage. The clumps of herbaceous plants and deciduous shrubs were dug in the field while dormant or semidormant and prepared for treatment by removing the loose soil and pruning the roots as extensively as was advisable.

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The evergreens were prepared for treatment by reducing the mass of soil about the roots to the minimum necessary to preserve the roots.

The small plants and root stocks were packed loosely in wire baskets in such a manner that liquid could circulate freely, but the larger plants were handled individually. The roots were completely immersed for 6 to 24 hours in emulsions containing from 0.1 to 3 g of carbon disulphide per liter. The temperature of the dilute emulsion was maintained between 65° and 70° F. during this period. The plants were then placed in storage for later planting, or set in the greenhouse, or in the field, according to the regular nursery procedure.

The experimental work involved the treatment of several different groups of plants, which, because of the variation in their nature, growing habits, and method of handling, will be considered individually.

ORNAMENTAL GRASSES

Some of the grasses, *Arrhenatherum bulbosum* (tuber oatgrass), *Arundo donax* (giant reed), *Elymus glaucus* (wild-rye), *Miscanthus sinensis gracillimus* (eulalia grass), *Cortaderia argentea* (pampasgrass), *Pennisetum alopecuroides* (pennistrum grass), and *Phalaris arundinacea* (reed canary grass), which are used for ornamental purposes were not seriously injured when the dormant roots were immersed for 24 hours in an emulsion containing 0.62 g of carbon disulphide per liter. As the dosage was increased, the injury became more extensive. Most of the plants were killed or seriously inhibited in subsequent growth by submersion for 24 hours in an emulsion containing 1 g of carbon disulphide per liter.

HERBACEOUS PERENNIALS

The field-grown clumps of certain of the hardy herbaceous plants were not seriously retarded in their subsequent growth by submersion, while dormant, for 24 hours in an emulsion containing 0.75 g of carbon disulphide per liter, although in some cases the bud scales and the sprouts were blackened to some extent by the treatment. Submersion in a concentration of 1 g of carbon disulphide per liter for even 6 hours usually seriously inhibited subsequent growth, and submersion in this dosage for longer periods was usually fatal. The varieties of perennials that the results indicate might be treated by using 0.75 g per liter for 24 hours are *Convallaria majalis* (lily-of-the-valley), *Dahlia* spp. (dahlias), *Hemerocallis dumortieri* (early daylily), *H. fulva* (tawny daylily), *Iris cristata* (crested iris), *I. germanica* (German iris), *I. japonica* (fringed iris), *I. ochroleuca* (yellowband iris), *I. pseudacoris* (yellowflag iris), *I. sibirica* (Siberian iris), *Paeonia albiflora* (Chinese peony), *P. officinalis* (common peony), *Phlox amoena* (amoena phlox), *P. paniculata* (garden phlox), and *Sedum spectabile* (showy stonecrop).

RHUBARB

The roots of common rhubarb (*Rheum rhaponticum*) were not appreciably affected by submersion for 24 hours in an emulsion containing 1 g of carbon disulphide per liter. Stronger doses, even for shorter periods of treatment, generally blackened the buds and injured the roots.

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DECIDUOUS SHRUBS

The roots of deciduous shrubs have been treated successfully by immersion in a dilute emulsion of carbon disulphide only when the plants were dormant. When the treatment was applied early in the spring before growth began, the shrubs were not usually inhibited to any appreciable extent in their subsequent development by immersion of the roots for 24 hours in an emulsion containing 0.75 g of carbon disulphide per liter. In some cases even higher dosages have been used successfully with dormant plants, but when the plants are growing, even lower dosages have seriously injured or killed them. The results indicate that the following species of deciduous shrubs, when dormant, might be treated in this manner: *Berberis thunbergi* (Japanese barberry), *Buddleia davidi* (orange-eye butterflybush), *Callicarpa purpurea* (Chinese beautyberry), *Calluna vulgaris* (heather), *Clethra alnifolia* (summersweet), *Cornus florida* (flowering dogwood), *Crataegus oxyacantha* (English hawthorn), *Deutzia gracilis* (slender deutzia), *Euonymus alatus* (winged euonymus), *Forsythia suspensa fortunei* (Fortune forsythia), *Hibiscus syriacus* (shrub-althea), *Hydrangea arborescens* (smooth hydrangea), *Ligustrum ovalifolium* (California privet), *Lonicera ledebouri* (honeysuckle), *Philadelphus coronarius* (sweet mockorange), *Rhus typhina* (staghorn sumac), *Rosa* spp. (rose), *Spiraea* spp. (spirea), *Symphoricarpos vulgaris* (coralberry), *Syringa vulgaris* (lilac), *Viburnum* spp. (viburnum), *Weigela rosea* (pink weigela).

DECIDUOUS TREES

The results obtained with deciduous ornamental trees indicate that the following species, when dormant, might be treated in the same manner as were the deciduous shrubs: *Acer* spp. (maple), *Aesculus hippocastanum* (horse-chestnut), *Betula alba* (European white birch), *Fagus sylvatica* (European beech), *Fraxinus ornus* (flowering ash), *Magnolia glauca* (sweetbay), *Morus alba* (white mulberry), *Quercus rubra* (red oak), *Salix babylonica* (Babylon weeping willow), *Sorbus aucuparia* (European mountain-ash), *Tilia vulgaris* (common linden), *Ulmus americana* (American elm).

BROAD-LEAVED EVERGREENS

The broad-leaved evergreens were generally injured at all seasons of the year by submerging the roots in dilute carbon disulphide emulsion. There was considerable variation in the effect of the treatment on different varieties of the same species, and often on the same variety when it was grown under different conditions. A dosage of 0.5 g of carbon disulphide per liter often killed or seriously injured from 10 to 60 percent of the plants treated for periods of 18 to 24 hours. Treatments of shorter duration at this dosage caused, to some extent, less injury; higher dosages generally caused extensive damage, even when the period of submersion was shortened to 6 hours. The results indicated that the following varieties of broad-leaved evergreens could *not* be treated in this manner without causing severe damage: *Azalea indica* (Indica azalea of the varieties Empress of India, Jean Haerens, Fred Sanders, Mme. Van der Cruyssen, Mme. Petrick, Simon Mardner, Prof. Walters, and Vervaene), *A. obtusa kuisiana* (Kurume azaleas of the varieties Apple Blossom, Bridesmaid, Christmas Cheer, Peach Blossom, Coral Bells, and Pink Pearl), *Buxus sempervirens* (common

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box), *Ilex crenata* (Japanese holly), *Kalmia latifolia* (mountain-laurel), *Pachysandra terminalis* (Japanese pachysandra), *Pyracantha coccinea* (scarlet firethorn), *Rhododendron catawbiense* (Catawba rhododendron).

NARROW-LEAVED EVERGREENS

The narrow-leaved evergreens that were treated were apparently as susceptible to the action of carbon disulphide when their roots were submerged in a dilute emulsion as were the broad-leaved evergreens under the same conditions. The treatments were generally unsuccessful when applied to the following species of narrow-leaved evergreens: *Abies concolor* (white fir), *Juniperus chinensis* (Chinese juniper), *J. communis* (common juniper), *J. excelsa* (Greek juniper), *J. horizontalis* (creeping juniper), *J. sabina* (Savin juniper), *J. virginiana* (red-cedar), *Picea canadensis* (white spruce), *P. excelsa* (Norway spruce), *P. pungens* (Colorado spruce), *P. rubra* (red spruce), *Pinus montana* (Swiss mountain pine), *P. nigra* (Austrian pine), *P. pungens* (table mountain pine), *P. resinosa* (red pine), *P. strobus* (white pine), *P. sylvestris* (Scotch pine), *Chamaecyparis obtusa* (Hinoki cypress), *C. pisifera* (Sawara retinospora), *C. pisifera filifera* (thread retinospora), *C. pisifera plumosa* (plume retinospora), *Taxus baccata* (English yew), *T. canadensis* (Canada yew), *T. cuspidata* (Japanese yew), *Thuja occidentalis* (American arborvitae), *T. orientalis* (oriental arborvitae), *Tsuga canadensis* (Canada hemlock).

POURING DILUTE EMULSION ON THE SOIL OF POTTED PLANTS TO DESTROY THE LARVAE

In preliminary experiments it was found possible to destroy third instar larvae in the soil about the roots of potted plants, without causing serious damage to the plants, by pouring a dilute emulsion of carbon disulphide on the surface and allowing the insecticidal liquid to percolate through the soil. Satisfactory results were obtained only when a volume of liquid equivalent to the volume of the soil in the pot was used. The destruction of the larvae under these conditions is limited by the temperature of the soil, the organic matter present, and the physical condition of the soil.

The influence of the soil temperature on the dosage necessary to destroy the larvae was determined by treating infested soil in 8-inch pots at different temperatures with different concentrations of emulsion at the same temperature as that of the soil until the minimum effective concentration was determined. In each case a volume of liquid (3 l) equivalent to the volume of the soil in the pots was applied. After 7 days the effect of the treatments on the larvae was determined. The minimum concentrations required to kill the larvae at the different temperatures are given in figure 29. It was found that when the soil temperature was 70° F. a concentration of 470 mg per liter was sufficient, but when the soil temperature was 32° a concentration of 1,100 mg of carbon disulphide per liter of emulsion was required.

There are many mixtures of soil used for growing potted plants in the commercial nurseries. The majority of plants require a well-drained soil with adequate water-holding capacity. An experiment was carried on at a temperature of 60° F. to determine the dosage of carbon disulphide per liter of emulsion required to kill larvae in different mixtures of clay loam and peat. As is shown in figure 30, the

concentration of carbon disulphide required depended upon the proportion of peat in the mixtures. A concentration of 620 mg of carbon disulphide per liter was effective in clay loam and in a mixture of clay loam containing 25 percent of peat by volume. A concentration of 1,100 mg was required in 100 percent of peat. The treatment of peat by this procedure is at best far from satisfactory owing to the fact that it is difficult to obtain a proper distribution of the chemical. Peat is loose, spongy, highly absorptive, and filled with numerous channels through which the liquid may drain. The proper dispersion was obtained only by using relatively large doses of carbon disulphide, and this introduces the hazard of destroying the plants.

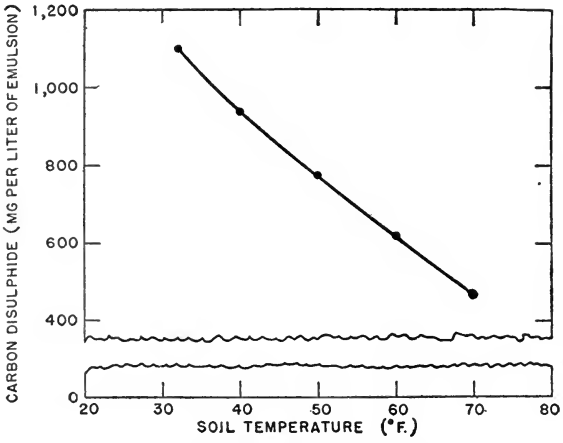

FIGURE 29.—Minimum effective concentrations of carbon disulphide emulsion at different soil temperatures for destroying third-instar larvae of the Japanese beetle in 8-inch pots of clay loam. A volume of dilute emulsion equal to the volume of the soil was poured on the top and allowed to percolate through the soil.

The condition of the soil and the development of roots in the pot modify to some extent the effectiveness of the treatment. When a large volume of liquid is applied to a plant soon after potting, before natural drainage has become established, there is a tendency for the soils containing clay to puddle and to remain water-logged for several days. The penetration of the emulsion through a soil in this condition is usually very slow and may require several hours. Insecticidal results are generally unsatisfactory under these conditions. When potted plants are allowed to stand until natural drainage has become established, this difficulty is largely overcome. If, on the other hand, plants are permitted to grow until the roots are potbound, the soil may become almost impervious to the emulsion. In general, satisfactory results were obtained with plants which were established, but not pot-bound, and growing in soil which was moist at the time of treatment.

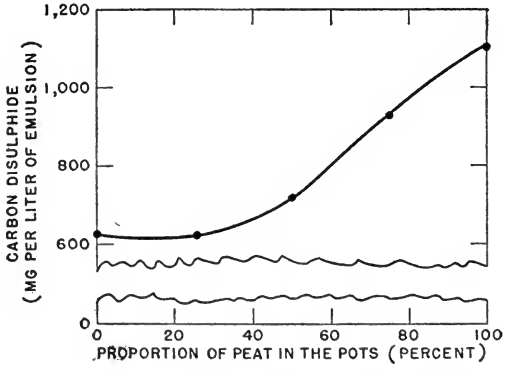

FIGURE 30.—Concentrations of carbon disulphide emulsion needed to kill third-instar larvae of the Japanese beetle in pots containing various proportions of clay loam and peat. A volume of emulsion equal to the volume of soil was poured on the top and allowed to percolate through the soil. Temperature of the soil and the emulsion, 60° F.

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In view of the encouraging results obtained in the destruction of the larvae, the treatment was applied to the Mexican cibotium, growing in 10-inch tubs. Dilute emulsion, ranging in concentration from 310 to 1,870 mg of carbon disulphide per liter and equivalent in volume to that of the soil in the tubs, was poured on the surface and allowed to percolate through the soil. The temperature during the period of treatment was approximately 70° F. One group of the treated plants was placed in partial shade and the other group in complete shade, for 3 days after treatment. The plants were kept under constant observation until the effect of the various treatments could be definitely determined. A dosage of 310 mg per liter caused no apparent injury, and dosages up to 780 mg caused only temporary drooping of the fronds. A concentration of 940 mg killed the plants. It was found that the tendency of the fronds to droop after treatment, because of the inability of the injured roots to supply the necessary quantity of water to the fronds, was overcome to a large extent by shading the plants and spraying them frequently with water for a few days following the treatment. In view of the fact that a dosage of 460 mg per liter was sufficient to destroy the larvae, it is apparent that a treatment using this concentration can be applied to the Mexican cibotium under these conditions without causing serious damage to the plants.

The treatment was also applied to the house hydrangea (*Hydrangea opuloides*), using concentrations ranging from 620 mg to 1,250 mg of carbon disulphide per liter of emulsion. One group of plants was treated early in September immediately after potting. The proper drainage had not been established in these pots, and the soil remained water-logged for several days. As a result, the plants treated with the emulsion, or even water, were severely damaged. At the same time the treatments were applied to hydrangeas which had been in pots for a sufficient time to allow normal drainage to become established. These suffered no injury. Potted hydrangeas were treated successfully in January, while dormant, and in March, only a few weeks before coming into bloom. As the hydrangeas were not seriously injured, even with a dosage of 1,250 mg, when the plants were properly established in the pots, this procedure appeared to be satisfactory for the destruction of larvae in the soil.

With the foregoing results as a basis, the treatment was applied in a commercial nursery to 1,500 Mexican cibotiums and 5,000 hydrangeas. These plants were well established in pots or tubs. As the temperature of the soil was about 60° F. a dosage of 620 mg of carbon disulphide per liter of emulsion was used. The plants were arranged in a single row on a level greenhouse bench; a volume of emulsion equivalent to the volume of soil was measured out for each pot, and beginning at one end of the line of pots the soil in each pot was flooded with as much emulsion as the pot would hold. When the first portion of the emulsion disappeared from the surface of the soil, the process was repeated until the required quantity had been applied to each pot. The first portion of the liquid usually disappeared rapidly, but each successive portion disappeared more slowly from the surface. The drainage was so poor in some of these pots that even the first portion of the emulsion did not disappear from the surface within 24 hours. The treatment was not considered to be satisfactory in pots that drained very slowly or very rapidly. The average time for the appli-

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cation of the liquid was about 6 hours. After treatment the plants were maintained for 48 hours at a temperature of 60° F. to assure the destruction of the larvae in the pots.

This procedure was successful in destroying the larvae without causing serious injury to the plants, but it was considered to be too slow and expensive to be practical in commercial greenhouses.

TREATMENT OF SOIL ABOUT NURSERY PLANTS BY FLOODING THE GROUND WITH THE EMULSION

French investigators (*8*), as early as 1875, used aqueous solutions of carbon disulphide to treat the soil of vineyards infested with the grape phylloxera (*Phylloxera vitifoliae* Fitch). Leach (*78*), in 1918, and Townsend (*147, 148*), in 1920, reported favorable results against the woolly aphid (*Eriosoma lanigerum* Hausm.) by pouring an aqueous solution of carbon disulphide into basins dug around the roots of the trees. Bordaz (*1*), in 1914, destroyed the white grub *Exophthalmus famelicus* in the soil about the roots of cacao and coffee plants with a dilute emulsion of the chemical by this procedure. In 1923 preliminary experiments by Leach et al. (*82, 85*) showed that a dilute emulsion of carbon disulphide could be used in this manner to destroy larvae of the Japanese beetle in the soil about the roots of nursery plants in the field.

PREPARATION OF PLANTS FOR TREATMENT

In applying the volume of emulsion necessary to kill larvae of the Japanese beetle about the roots of a plant in a nursery, it was necessary to prepare a basin around the base of the plant in order to confine the insecticide to the area to be treated. The trash and weeds were removed and the surface of the ground leveled to permit a uniform distribution of the emulsion over the surface, as shown in figure 31, *A*. The lower branches of the plant were tied up, if drooping, to prevent the foliage from coming into contact with the insecticide. Then a strip of galvanized iron, 9 inches in width and of the necessary length, was bent around the base of the plant, with the ends overlapping, to enclose an area greater in diameter than the mass of soil to be dug with the plant. This strip was forced into the ground to a depth of 3 inches, and the soil was carefully firmed on both sides of the metal as shown in figure 31, *B*. As an added precaution soil was sometimes banked up against the outside of the metal strip to a height of 3 or 4 inches.

PENETRATION OF EMULSION INTO THE GROUND

When experiments were begun in 1923 to determine the minimum volume of water and the concentration of emulsified carbon disulphide necessary to destroy third-instar larvae in the soil about the roots of plants in the field, it was found that few plants in the commercial nurseries were infested naturally with a sufficient number of larvae to be of experimental value. It was necessary to infest plants artificially. It is obvious that larvae could not be placed within the area to be treated by making holes from the surface, as this would disturb the natural condition of the soil and make a direct channel for the emulsion to penetrate to the insects. The soil was therefore infested artificially in the following manner in these early experiments and in

the later experiments where there was not a sufficient number of larvae naturally in the soil: A trench was dug at some distance from the area enclosed with the strip of galvanized iron, and holes 1½ inches in diameter were bored by means of a soil auger, parallel to and 6, 12, and 18 inches below the surface, until the tunnels came

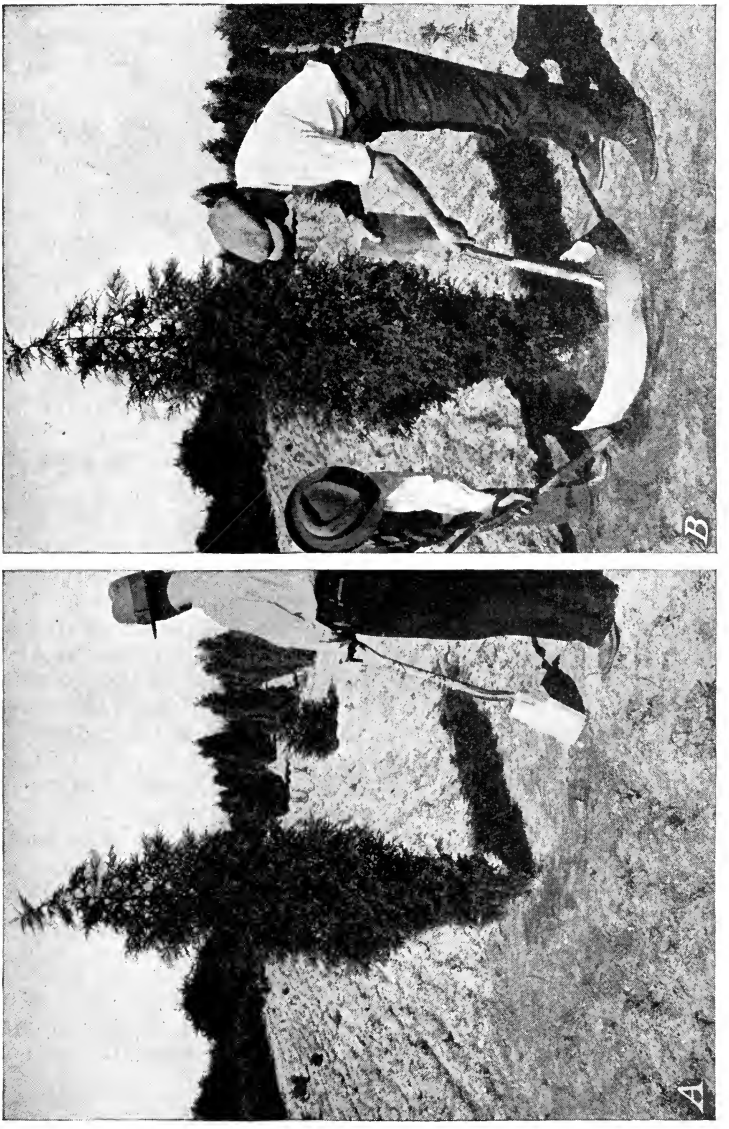

FIGURE 31.—Steps in destroying larvae of the Japanese beetle in the soil about the roots of a tree that is to be taken up for shipment: *A*, The ground is cleared of weeds and trash and leveled; *B*, a collar of galvanized iron is put around the tree and forced about 3 inches into the ground and the earth packed tightly against it.

within the area to be treated. Cylindrical wire cages 1¼ inches in diameter and 6 inches long, as shown in figure 1, *C*, containing soil and larvae, were pushed into the holes under the area enclosed by the galvanized iron. The holes were then tightly packed with soil and the trench refilled.

With the artificial infestation obtained in this manner, dilute emulsions, ranging in concentration from 940 to 1,560 mg of carbon disulphide per liter, were applied to the surface, as shown in figure 32, *A*, at the rates of 1.8, 2.4, 3, and 3.6 gallons per square foot. The temperature of the soil at a depth of 6 inches was between 40° and 50° F. during these tests. At the end of 48 hours the larvae were removed from the treated soil and the effect of the various treatments determined. The tree was dug and prepared for shipment, as shown in figure 32, *B*. The penetration of the emulsion into the soil is recorded in figure 33.

The larvae were destroyed to a depth of 6 inches by applying to each square foot of soil 1.8 gallons of an emulsion containing 1,400 mg of carbon disulphide per liter, or 2.4 gallons of a concentration of 1,100 mg. Three gallons of emulsion containing 1,225 mg of carbon disulphide per liter killed all larvae to a depth of 12 inches below the surface and an equal volume containing 1,375 mg was completely effective when the larvae were 18 inches below the surface.

In view of the fact that practically all the larvae are found within 6 inches of the surface of the ground in nurseries during the growing season, treating the ground at the rate of 1.8 gallons to a square foot with an emulsion containing 1,400 mg of carbon disulphide per liter, or with 2.4 gallons at 1,100 mg should be effective in destroying the larvae about the roots of nursery stock. To allow for the great variation in soils it was considered desirable to use not less than 2.4 gallons of the emulsion to each square foot of ground.

LATERAL DIFFUSION OF EMULSION IN SOIL

The lateral diffusion of the emulsion or of the vapor evolved from the emulsion in the soil is of particular interest in nurseries on sloping ground, where it is difficult to cover all of the area to be treated with the emulsion. A study was made of the lateral diffusion of the emulsion by placing larvae at points 3, 6, 9, and 12 inches outside the galvanized-iron strips. The soil was rather dry at the time of treatment, which made it possible to determine approximately the lateral flow of the emulsion. It was found that at a depth of 6 inches the soil was wet to a distance of only 2 inches outside the treated area, and at a depth of 12 inches the soil was wet for a distance of 6 inches beyond the limits of the area to which the emulsion was applied. Some larvae within 3 inches of the treated area were killed, but in most cases the larvae were not affected by the emulsion. In a series of tests on sloping ground it was found that larvae were not killed in that portion of the area not covered by the emulsion.

It is apparent that the lateral diffusion of the emulsion in the soil is practically negligible. The insecticidal action in the field is confined to the area of ground covered by the emulsion. It is important, therefore, that all portions of the ground to be freed of larvae be covered with the insecticidal solution.

EFFECT OF SOIL TEMPERATURE ON THE MINIMUM LETHAL CONCENTRATION OF CARBON DISULPHIDE IN THE EMULSION

The concentration of carbon disulphide in an emulsion necessary to destroy the larvae at a depth of 6 inches in the soil depends, in a large measure, upon the temperature of the soil. A series of tests

were made to determine the concentrations required to kill larvae at temperatures ranging from 40° to 65° F. The results of these tests, which are summarized in figure 34, showed that when the emulsion was applied at the rate of 2.4 gallons per square foot, the minimum

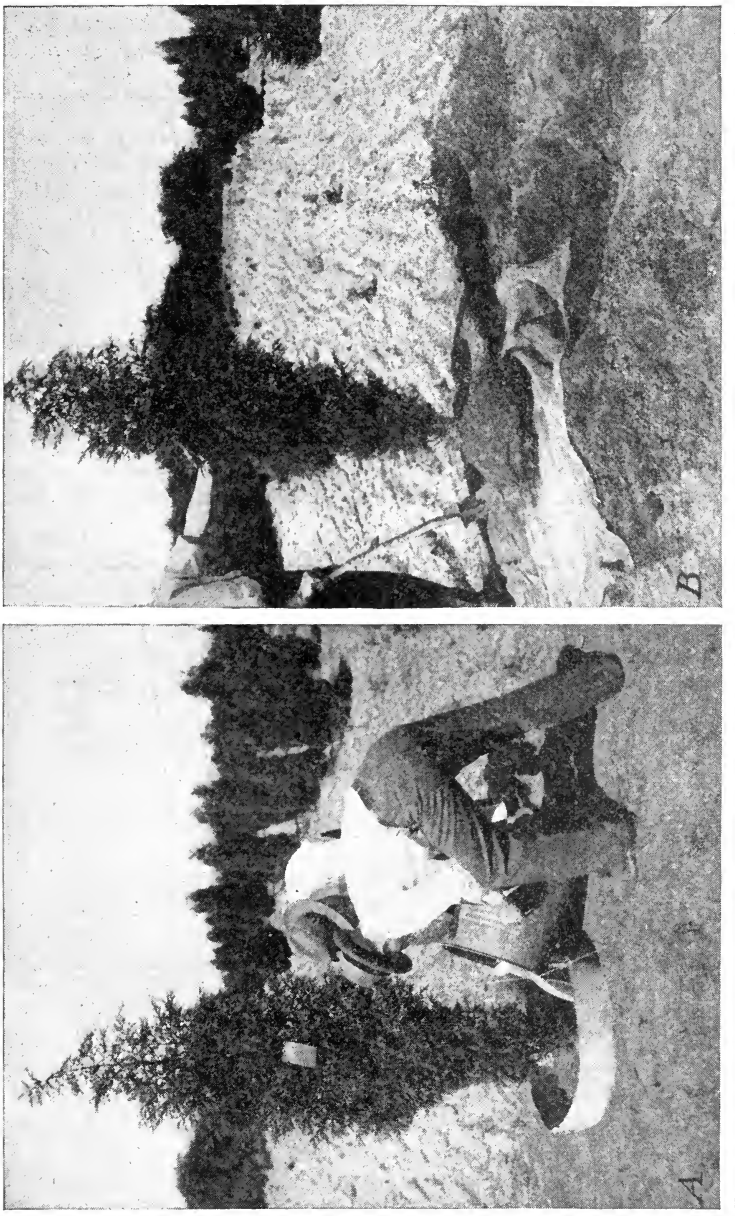

FIGURE 32.—Final steps in destroying larvae of the Japanese beetle about the roots of a tree that is to be taken up for shipment: *A*, Pouring carbon disulphide emulsion into the enclosed area; *B*, the soil ball dug and ready for tying up.

effective concentration ranged from 1,125 mg of carbon disulphide per liter at a temperature of 40° to 625 mg at a temperature of 65°. For the treatment to be successful, it is necessary that the tempera-

ture of the soil be not below the minimum temperature at which the concentration has been determined to be effective for a period of 48 hours.

As it is desirable, in order to avoid excessive injury to plants, to apply no larger doses of carbon disulphide than necessary to kill the larvae, it is necessary to determine the soil temperature at a depth of 6 inches for several days prior to treatment in order to anticipate the

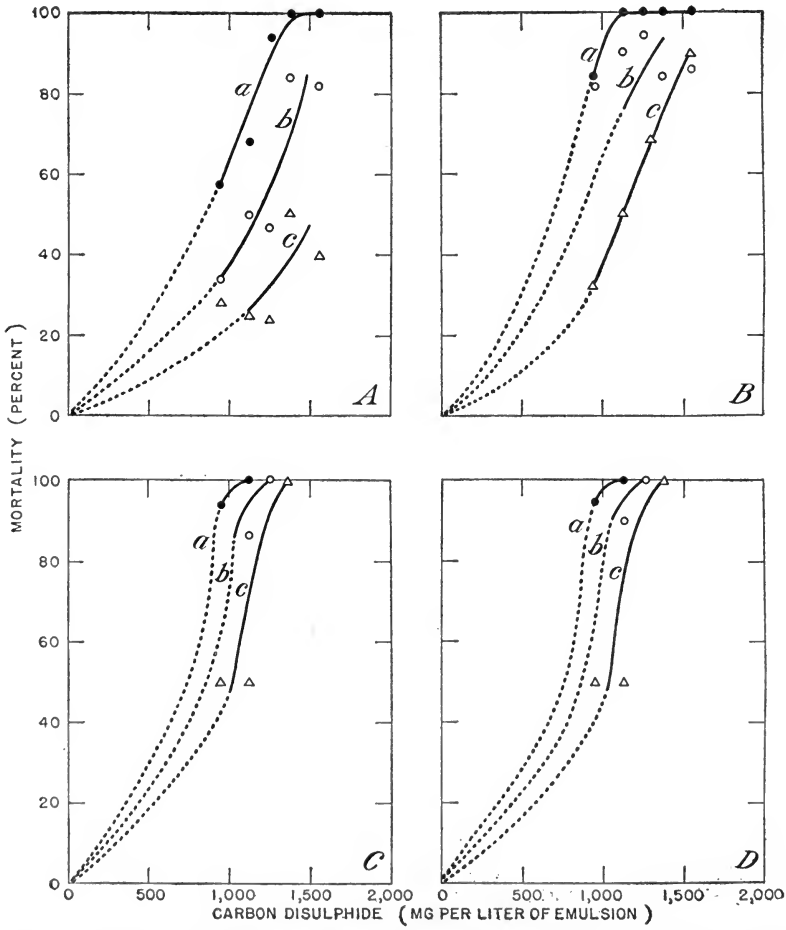

FIGURE 33.—Effect of concentration of carbon disulphide and the volume of emulsion on the lethal action against third-instar larvae of the Japanese beetle at *a*, 6-inch, *b*, 12-inch, *c*, 18-inch depths below the surface of the soil. Sandy loam; temperature at depth of 6 inches, 40°–50° F. *A*, 1.8 gallons per square foot; *B*, 2.4 gallons per square foot; *C*, 3 gallons per square foot; *D*, 3.6 gallons per square foot.

possible minimum temperature which might be encountered in the 48-hour period following the application of the emulsion. In the spring the concentration of carbon disulphide per liter of emulsion may well be increased to 1,250 mg per liter for a soil temperature of 40° F. As the temperature of the soil decreases in the fall, the strength of the emulsion has to be increased gradually to compensate for the lowering temperature. The results were unsatisfactory when

the temperature of the soil was below 40°, probably because of the inactivity of the insect.

EFFECT OF THE CONDITION OF THE SOIL ON THE INSECTICIDAL ACTION OF THE EMULSION

The physical condition of the soil at the time of application influences, to an important degree, the effect of the emulsion on the larvae. The most favorable insecticidal action is obtained in readily permeable soils with a relatively impermeable subsoil just below the infested layer that will prevent a rapid drainage of the emulsion. When soil is deep and permeable, the emulsion may drain away from the infested area too rapidly to be effective. On the other hand, when a soil is not permeable and the emulsion disappears slowly from the surface, a considerable portion of the chemical may be lost by evaporation and the concentration reduced below the minimum required to kill the larvae.

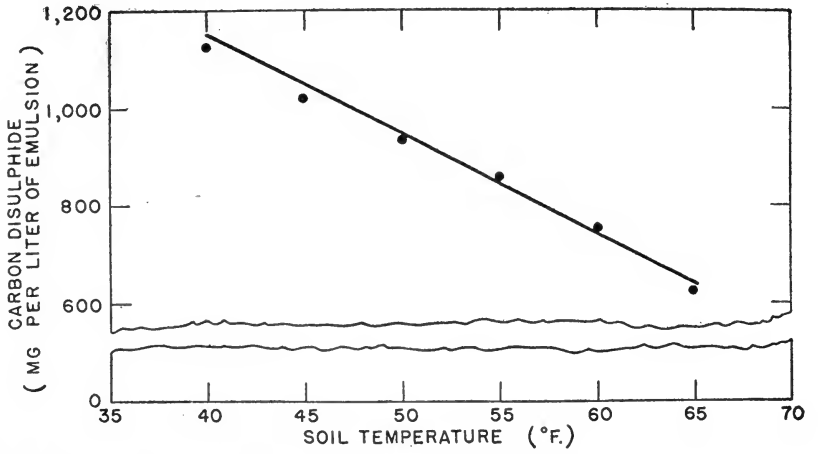

FIGURE 34.—Concentration of carbon disulphide in emulsion required to kill third-instar larvae of the Japanese beetle 6 inches below the surface at different soil temperatures. Emulsion applied at the rate of 2.4 gallons per square foot.

In general, land is not favorable for treatment when it is not in a proper condition for growing plants. Good results cannot be obtained on water-logged or excessively stony ground. Sandy soils are usually in condition for treatment at any time during the growing season, but clay soils may be wet and practically impervious to the emulsion or dry and full of lumps and crevices which will not permit uniform dispersion of the insecticide. Although on well-drained land good result have been obtained by applying the emulsion after a rain when ths soil was practically saturated with water, the soil is usually mose favorable for treatment when it is neither excessively wet nor ext cessively dry.

A study was made of the effect of the rate at which the emulsion disappeared from the surface of the ground on the insecticidal action and on the loss by evaporation of the chemical. A series of 138 plots in a fallow field in good condition were treated with the emulsion at the rate of 2.4 gallons per square foot. At the same time several pans, approximately 5 inches deep and 12 inches square, were placed

on the ground and filled with the emulsion to a depth of 4 inches. The air temperature during the 8 hours of the experiment ranged from 60° to 78° F., and a gentle breeze, not sufficient to disturb the surface of the liquid, was blowing. A careful record was made of the time required for the emulsion to disappear from the surface in each plot, and at intervals the concentration of carbon disulphide in the emulsion in the pans was determined. After 48 hours, the larvae were removed from the treated plots and the effect of the treatment determined. The results of this experiment are given in figure 35.

It was found that when the emulsion disappeared from the surface within 3½ hours, less than 10 percent of the carbon disulphide had been lost by evaporation, and the rate of penetration was not a factor in modifying the insecticidal action. As the period of penetration extended beyond 3½ hours, the insecticidal action was gradually reduced. On those plots where the emulsion did not disappear from the surface until 6½ hours, 17.5 percent of the emulsion was lost by evaporation and the mortality of the larvae was 17 percent less.

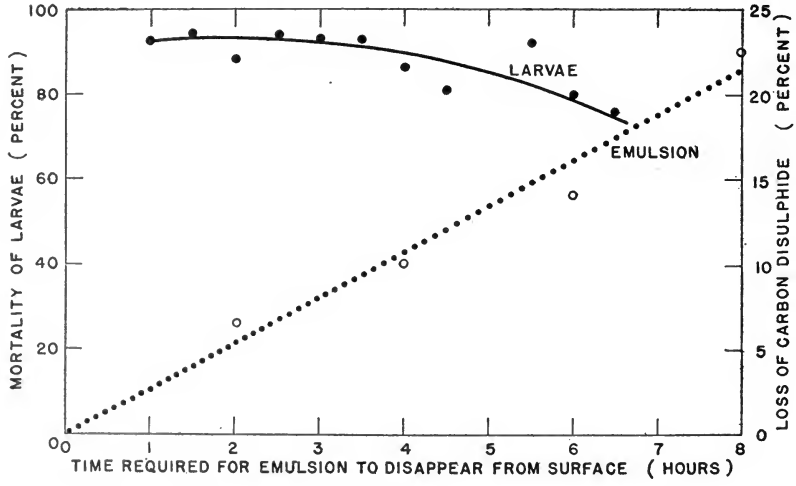

FIGURE 35.—The effect of the rate at which the emulsion disappears from the surface of the ground on the mortality of the larvae and on the loss of the chemical by evaporation.

In some cases satisfactory results have been obtained when as long as 5 hours elapsed before the emulsion disappeared, but penetration extended over this period does not give consistent mortality.

EFFECT OF THE EMULSIFIER ON THE EFFICIENCY OF THE EMULSIONS IN THE FIELD

It was anticipated from the data given in figure 11 that there would be little difference in the effectiveness of the emulsions containing sodium oleate-rosin soap, cottonseed-oil soap, peanut-oil soap, and castor-oil soap and probably poorer results would be obtained with emulsions containing corn-oil soap, potassium oleate soap, coconut-oil soap, and sodium oleate-rosin-beta-naphthol soap. Emulsions containing 750 mg of carbon disulphide per liter were prepared with rosin-fish oil soap (formula 2), sodium oleate-rosin soap (formula 5), sodium oleate-rosin-beta-naphthol soap (formula 6), potassium oleate soap (formula 7), castor-oil soap (formulas 9 and 10), cottonseed-oil

soap (formula 12), coconut-oil soap (formula 13), peanut-oil soap (formula 14), and corn-oil soap (formula 15). These emulsions were applied at the rate of 2.4 gallons per square foot to plots of artificially infested clay loam. After 48 hours the larvae were removed from the different plots and the effect of each treatment determined. The mortality obtained with the emulsion containing sodium oleate-rosin soap (formula 5) was taken as a standard, and the mortalities obtained with the other emulsions were expressed in terms of the standard by dividing the mortality in each case by the mortality in the standard and multiplying by 100. The results of this study are given in figure 36.

It was found that emulsions containing sodium oleate-rosin soap, castor-oil soap, rosin-fish oil soap, potassium oleate soap, and peanut-

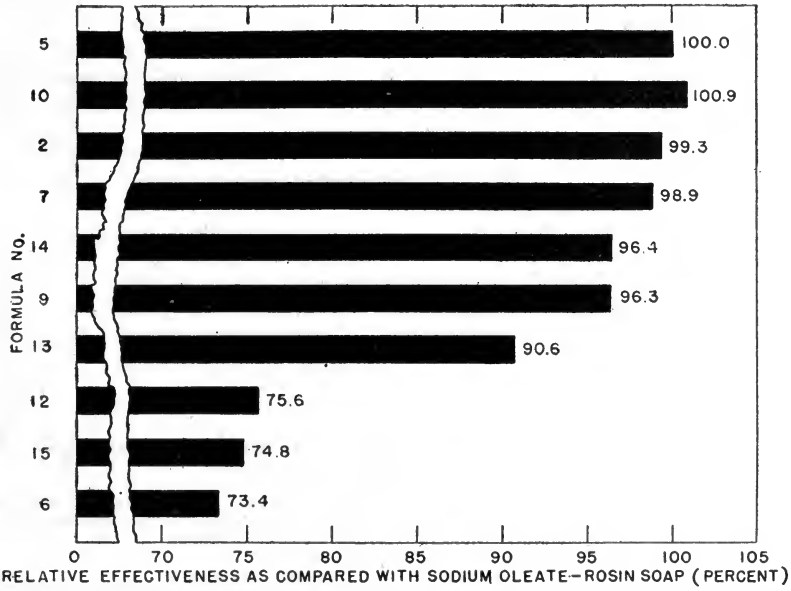

FIGURE 36.—Effect of emulsifier on insecticidal action of carbon-disulphide emulsion in the field: *5*, Sodium oleate-rosin soap (standard); *2*, rosin-fish oil soap; *6*, sodium oleate-rosin-beta-naphthol soap; *7*, potassium oleate soap; *9*, castor-oil soap; *10*, castor-oil soap; *12*, cottonseed-oil soap; *13*, coconut-oil soap; *14*, peanut-oil soap; *15*, corn-oil soap.

oil soap as emulsifiers were practically equal in effectiveness. The emulsion containing coconut-oil soap as an emulsifier was 90.6 percent as effective as the standard. The emulsions containing cottonseed-oil soap, corn-oil soap, and sodium oleate-rosin-beta-naphthol soap were considerably less effective. When the proportion of castor-oil soap was increased from 50 percent (formula 10) to 65 percent (formula 9) by volume, the effectivenses of the emulsion was decreased from 100.9 to 96.3. Even though a definite concentration of carbon disulphide is in the emulsion, the insecticidal action is modified by the type and the proportion of the emulsifier used. It is important, therefore, before an emulsion is used, that the insecticidal value be definitely established.

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DEPENDABILITY OF TREATMENT UNDER FIELD CONDITIONS

A study was made in a nursery of the dependability of the treatment in destroying the larvae under favorable soil conditions. The observations were limited to those tests where the soil remained for 48 hours after application of the emulsion within the range of temperature at which the dosage applied had been determined to be effective and the following conditions were obtained: Level ground; no seepage of liquid under the galvanized-iron collar; no soil conditions such as hardpan, rock formation, or high water table to prevent uniform penetration of the emulsion; and where the emulsion disappeared from the surface in not less than 10 minutes nor more than 5 hours. The frequency in percentages, at which different mortalities were obtained in 138 tests in which the treatment appeared to have been applied in a proper manner to ground favorable for a successful treatment is shown in figure 37.

It was found that all the larvae were killed in 25 percent of the tests, that 85 percent of the larvae were killed in 80 percent of the tests, and that at least 52 percent were killed in all tests. It is

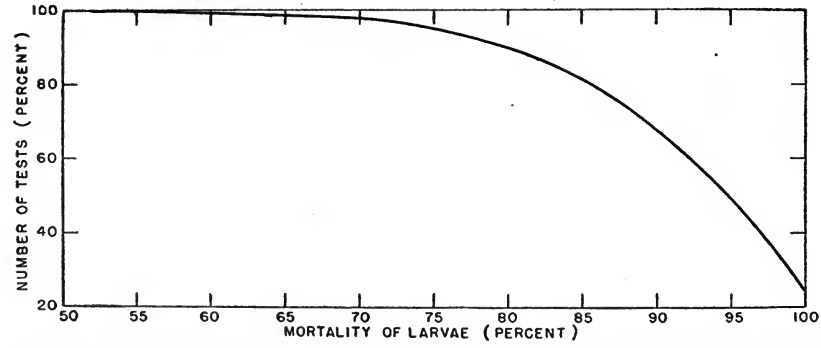

FIGURE 37.—Cumulative frequency curve indicating, by the distribution (in percentages) of 138 nursery tests, the effectiveness of carbon disulphide emulsion, applied at the rate of 2.4 gallons per square foot, in killing third-instar larvae of the Japanese beetle 6 inches below the soil surface.

apparent that, with so many factors in open field soil beyond control, it is practically impossible to apply a treatment with the emulsion that can be depended upon absolutely to destroy the larvae of the Japanese beetle, even under apparently the most favorable conditions.

The effectiveness of this treatment was also carefully checked in the commercial nurseries by plant-quarantine inspectors of the United States Department of Agriculture during the period from 1925 to 1930, inclusive. The mortality of the larvae reported during each season under all types of nursery conditions is summarized in figure 38. It was found that the seasonal mortality of the larvae ranged from 74.5 to 98 percent. No difference could be determined between the effectiveness of the treatment in the spring and in the fall. During this period the formula of the emulsion was changed several times with the object of improving the effectiveness of the treatment and reducing the injury to the plants. Formula 7, which was used in the spring of 1925, was discontinued because it was suspected that the presence of the alcohol caused injury to the plants; formula 5, which was substituted for formula 7, formed a rather

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viscous material that was difficult to measure accurately in small quantities and it was replaced in the spring of 1928 by formula 9. When it was suspected that the proportion of emulsifier in formula 9 was too high it was in turn replaced in the fall of 1929 by formula 10. It was believed that the variation in the effectiveness of the treatment might be attributed to the difference in the effectiveness of the different emulsions, but an examination of the data in figure 38 for the treatments following this last change in formula shows that the wide range in the effectiveness of the treatment is not related to the formula of the emulsion. The experiment outlined in figure 36,

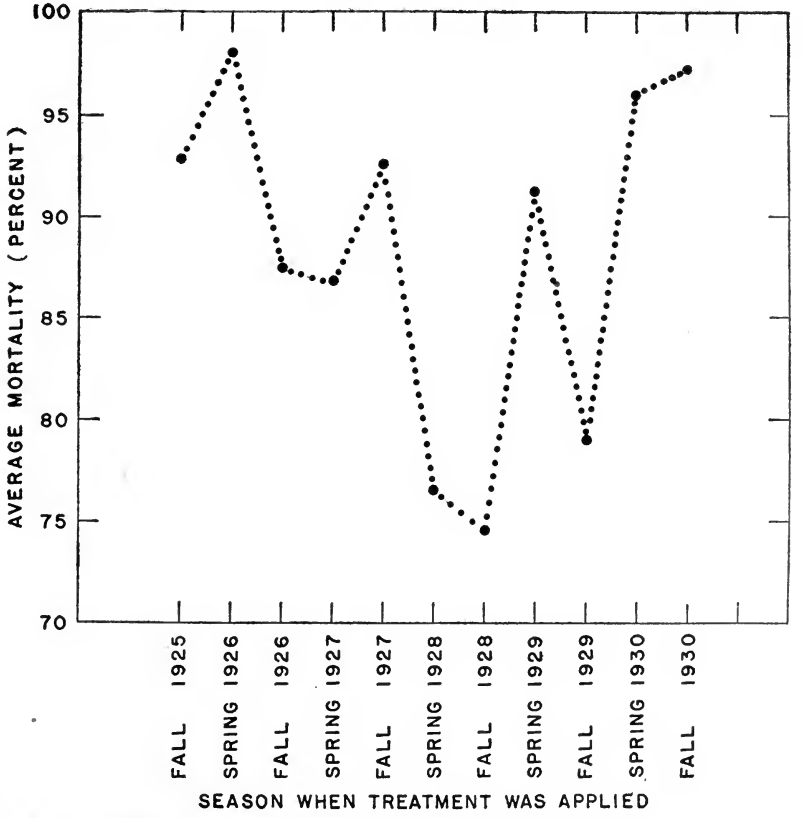

FIGURE 38.—The effectiveness of carbon disulphide emulsion treatment in killing larvae in commercial nurseries at different seasons of the year.

where these emulsions were tested under the same conditions, indicated that there was little difference in the insecticidal action of these emulsions in the soil. The difference in the effectiveness of the treatment is probably caused by the seasonal variation in the condition of the soil at the time of treatment.

The effectiveness of the treatment in the commercial nurseries, when it is based on larval mortality, does not, however, give a complete picture of the situation. During the season of 1930, for example, the treatment was applied to 3,766 plants in two nurseries. At the time of digging it was found that 1,652, or 43.9 percent, of these

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plants had been infested, but in only 81, or 4.9 percent, of the infested plants had the emulsion failed to kill all of the larvae in the soil about the roots. It might be considered, therefore, that the treatment under favorable conditions in the commercial nurseries can be expected to destroy the infestation in about 95 percent of the stock.

TOLERANCE OF NURSERY PLANTS TO EMULSION POURED ON THE SOIL ABOUT THEIR ROOTS IN THE FIELD

The concentration and the volume of emulsion which can be poured on the soil about the roots of plants in the field is limited by the minimum quantity necessary to kill the larvae and the maximum quantity tolerated by the plants. In most cases these two values are nearly equal.

A study was made of the tolerance of different varieties of plants growing on a sandy loam to the treatment with the emulsion. The emulsion was applied at the rate of 2.4 gallons per square foot. When the soil temperature was between 40° and 50° F., a concentration of 1,250 mg of carbon disulphide per liter was used; when the temperature was between 50° and 60°, the concentration was 937 mg; and when between 60° and 70°, the concentration was 750 mg. After the treatment the plants were dug and handled according to the usual nursery procedure.

In these preliminary treatments, in the spring and in the fall, when the plants were not growing vigorously, specimens of the following species were treated in this manner without causing a more serious check in their subsequent growth than was caused by normal methods of transplanting:

Broad-leaved evergreens:	
Azalea amoena	Amoena azalea.
Azalea hinodegiri	Hinodegiri azalea.
Azalea kaempferi	Torch azalea.
Buxus sempervirens	Common box.
Rhododendron catawbiense	Catawba rhododendron.
Narrow-leaved evergreens:	
Abies concolor	White fir.
Chamaecyparis pisifera	Sawara retinospora.
Juniperus chinensis	Chinese juniper.
Juniperus communis	Common juniper.
Juniperus excelsa	Greek juniper.
Picea excelsa	Norway spruce.
Picea pungens	Colorado spruce.
Pinus strobus	White pine.
Pinus sylvestris	Scotch pine.
Taxus canadensis	Canada yew.
Taxus cuspidata	Japanese yew.
Thuja occidentalis	American arborvitae.
Thuja orientalis	Oriental arborvitae.
Tsuga canadensis	Canada hemlock.
Deciduous plants:	
Hydrangea opuloides	House hydrangea.
Lonicera sp	Honeysuckle.
Rosa wichuraiana (hybrid)	Dorothy Perkins rose.
Syringa vulgaris	Common lilac.

EFFECT OF THE VIGOR OF THE PLANT ON THE SUSCEPTIBILITY TO INJURY

When carbon disulphide emulsion is applied to the soil about a plant, most of the rootlets touched by the emulsion are killed; thus for a time the absorptive capacity of the root system is decreased

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and the growth of the plant arrested. If the destruction of the rootlets is extensive, or the plant does not have sufficient vigor to replace them, the treatment may prove fatal to the plant.

It has been observed with hemlock, spruce, arborvitae, hydrangea, and azalea that the root systems of plants that were weak before treatment were badly injured and the revival of growth was tardy. Strong plants, or plants that have only slight injury to the root system, appear to endure the short suspension in the functions of the roots without suffering any serious damage.

EFFECT OF SEASON ON THE SUSCEPTIBILITY OF PLANTS TO INJURY

The effect of emulsified carbon disulphide on plants at different seasons of the year was studied by treating plants at different stages of their activitity during the growing season. The Canada hemlock

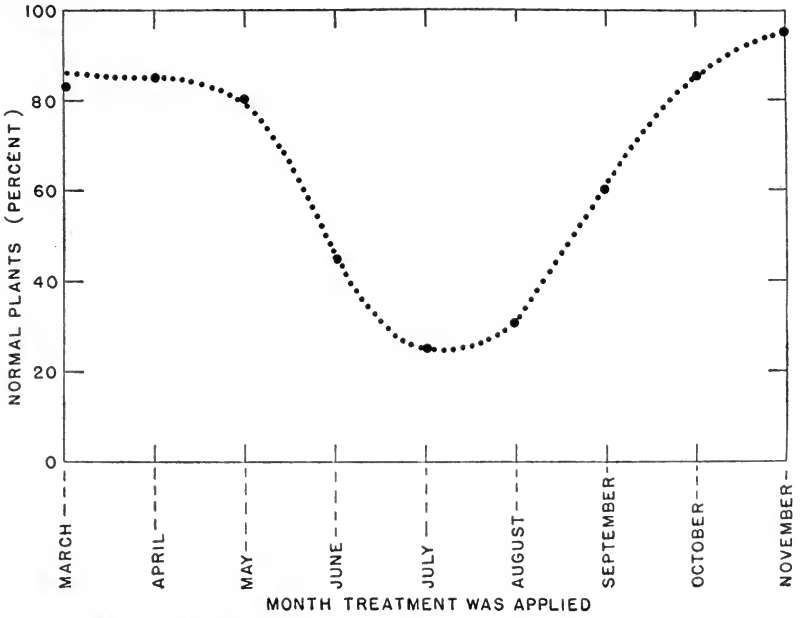

FIGURE 39.—Effect of the season on the number of Canada hemlock (*Tsuga canadensis*) surviving the application of insecticidal doses of carbon disulphide emulsion to the soil.

was chosen for this study, because it appeared to be one of the plants most susceptible to injury. Groups of hemlock approximately 3 feet in height were treated between March and November 1926 with an insecticidal dose of emulsified carbon disulphide. The trees were not disturbed after treatment, but were left in the nursery row for observation. The effect of the treatments, determined by examination in May 1927, are shown graphically in figure 39. It is obvious that hemlock is most susceptible to the action of emulsified carbon disulphide when it is growing vigorously in June and during the warm months of July and August, and that it is least susceptible to injury during March, April, May, October, and November. When treatment is applied during the spring or fall it would be expected that less than 20 percent of these plants would be injured.

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INFLUENCE OF SOIL ON INJURY TO PLANTS IN THE FIELD BY THE EMULSION

The effect of dilute carbon disulphide emulsion on Canada hemlock has also led to a better appreciation of the influence of the soil on the degree of injury. Groups of hemlock, of the same size as those used in determining the relation between the season and the degree of injury, growing on a heavy clay loam and on a light sandy loam were treated during September 1923. A previous examination of the root systems showed that in the sandy loam the roots had spread extensively, whereas in the clay loam the roots were shallow and restricted. In November an examination of these trees showed that 35 percent were dead or severely injured in the sandy loam and 52 percent were dead or severely injured in the clay loam.

The difference in the effect of the treatment may be attributed to two factors, namely, the difference in the root systems and the time the emulsion was in contact with the roots. In the clay soil the bulk of the roots were within 12 inches of the surface, whereas in the sandy loam the roots went to a depth of 18 or 20 inches. The emulsion disappeared from the surface of the sandy loam in approximately 1½ hours, while 4 hours was required for it to go into the clay soil. The insecticide in this latter case was probably removed by the upper layers of soil. The root system as a whole in the clay loam, therefore, would be exposed to a greater concentration of the insecticide for a longer period than the root system in the sandy loam, and therefore suffer more injury.

EFFECT OF THE EMULSIFIER ON THE INJURY TO PLANTS

A series of experiments was carried on in June 1926 with 250 Norway spruce to study the influence of the emulsifier on the action of the emulsion on the plants in the nursery. The trees were about 4 feet in height and were growing on a light loamy sand. The different emulsifiers used to prepare the stock emulsions were rosin-fish oil soap (formula 2), sodium oleate-rosin soap (formula 5), sodium-oleate-rosin-beta naphthol soap (formula 6), and alcoholic potassium oleate soap (formula 8). Dilute emulsions containing 0.5, 0.6, 0.8, 0.9, and 1.1 g of carbon disulphide per liter were prepared from each of these stock emulsions and applied to the soil about the roots of the trees, 2.4 gallons being used to each square foot of ground. Forty-eight hours after treatment the trees were dug (but replanted in their original positions) in order to prevent any roots which might be outside the treated area from sustaining the growth.

An examination of the trees a month later showed that a large proportion of the rootlets had been killed by all the emulsions. At this time little difference was observed between the effects of the 0.5-g and 1.1-g dilutions. The final examination was made 3 months after the application of the emulsions. There appeared then to be little difference in the reaction of the trees to the different concentrations. In the summary of the effect of the emulsifier, all the trees treated with the emulsion containing a certain emulsifier were considered as a group. The reaction of Norway spruce to the different emulsions at the end of 3 months is shown in table 4.

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TABLE 4.—*Effect at the end of 3 months of emulsions made up with different emulsifiers on Norway spruce, Moorestown, N. J., 1926*

Emulsifier	Effect on trees	
	Percent dead	Percent alive
Rosin-fish oil soap	18	82
Sodium oleate-rosin soap	32	68
Alcoholic potassium oleate soap	38	62
Sodium oleate-rosin-beta naphthol soap	44	56

There was a considerable difference in the resistance of the individual trees to the emulsions, and in the rate of recovery after treatment. It appears, however, that the emulsifier does affect the degree of injury caused by emulsified carbon disulphide. The mortality of the trees treated with the emulsion containing rosin-fish oil soap as an emulsifier was less than with the other emulsions, and the highest mortality occurred where sodium oleate-rosin-beta naphthol soap was used as the emulsifier.

VARIETIES OF STOCK TREATED WITH CARBON DISULPHIDE EMULSION IN THE FIELD AT COMMERCIAL NURSERIES

The treatment with carbon disulphide emulsion in the field has been applied in commercial nurseries to many varieties of plants with apparently no more injury to the plants, in general, than is normally caused by transplanting. It has been the general experience that healthy plants, treated in the early spring or in the fall when the plants are not growing actively, are not seriously injured. A report by V. A. Johnson of this Bureau shows that 71,721 plants of the following varieties have been treated prior to shipment during the period from 1925 to 1930, inclusive:

Abelia chinensis	Chinese abelia.
grandiflora	Glossy abelia.
Abies arizonica	Cork fir.
cephalonica	Greek fir.
cephalonica apollinis	Apollo fir.
cilicica	Cilician fir.
concolor	White fir.
homolepis	Nikko fir.
lasiocarpa	Alpine fir.
nordmanniana	Nordmann fir.
pectinata	Silver fir.
veitchi	Veitch fir.
Acer ginnala	Amur maple.
japonicum	Fullmoon maple.
palmatum	Japanese maple.
platanoides	Norway maple.
saccharum	Sugar maple.
Aesculus hippocastanum	Horsechestnut.
Amelanchier sp	Shadblow.
Amygdalus persica	Peach.
Arundinaria japonica	Arrow bamboo.
Azalea amoena	Amoena azalea.
arborescens	Sweet azalea.
calendulacea	Flame azalea.
hinodegiri	Hinodegiri azalea.
indica	Indica azalea.
japonica	Japanese azalea.

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Azalea kaempferi	Torch azalea.
ledifolia	Snow azalea.
mollis	Chinese azalea.
nudiflora	Pinxterbloom.
pontica	Pontic azalea.
poukhanensis	Korean azalea.
schlippenbachi	Royal azalea.
vaseyi	Pinkshell azalea.
viscosa	Swamp azalea.
yodogawa	Yodogawa azalea.
Benzoin aestivale	Spicebush.
Betula populifolia	Gray birch.
Buxus japonica	Japanese box.
sempervirens	Common box.
Calluna vulgaris	Heather.
Carpinus betulus	European hornbeam.
caroliniana	American hornbeam.
Cedrus atlantica	Atlas cedar.
libani	Cedar of Lebanon.
Cercis canadensis	American redbud.
chinensis	Chinese redbud.
Chamaecyparis nootkatensis	Nootka cypress.
obtusa	Hinoki cypress.
pisifera	Sawara retinospora.
thyoides	Whitecedar.
Chionanthus virginica	White fringetree.
Cornus alba	Tartarian dogwood.
florida	Flowering dogwood.
kousa	Kousa dogwood.
mas	Cornelian-cherry.
paniculata	Gray dogwood.
stolonifera	Red-osier dogwood.
Corylopsis pauciflora	Buttercup winterhazel.
Corylus americana	American hazelnut.
Cotoneaster francheti	Franchet cotoneaster.
horizontalis	Rock cotoneaster.
rotundifolia	Roundleaf cotoneaster.
Crataegus coccinea	Thicket hawthorn.
cordata	Washington hawthorn.
crusgalli	Cockspur hawthorn.
mollis	Downy hawthorn.
oxyacantha	English hawthorn.
punctata	Dotted hawthorn.
Cryptomeria japonica	Common cryptomeria.
Cydonia japonica	Flowering quince.
Daphne cneorum	Rose daphne.
Enkianthus campanulatus	Redvein enkianthus.
perulatus	White enkianthus.
Euonymus alatus	Winged euonymus.
americanus	Brook euonymus.
japonicus	Evergreen burning bush.
Fagus grandifolia	American beech.
sylvatica	European beech.
Fatsia japonica	Fatsia.
Forsythia intermedia	Border forsythia.
suspensa	Weeping forsythia.
viridissima	Greenstem forsythia.
Ginkgo biloba	Maidenhair-tree.
Hibiscus syriacus	Shrub-althea.
Ilex aquifolium	English holly.
crenata	Japanese holly.
glabra	Inkberry.
opaca	American holly.
serrata	Finetooth holly.
Juglans sp.	Walnut.

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Juniperus chinensis	Chinese juniper.
communis	Common juniper.
excelsa	Greek juniper.
horizontalis	Creeping juniper.
japonica	Japanese juniper.
procumbens	Procumbent juniper.
sabina	Savin.
scopulorum	Colorado juniper.
squamata meyeri	Meyer juniper.
virginiana	Redcedar.
Kalmia latifolia	Mountain-laurel.
Kerria japonica	Kerria.
Koelreuteria paniculata	Goldenrain-tree.
Larix europaea	European larch.
leptolepis	Japanese larch.
Leucothoe catesbaei	Drooping leucothoe.
Ligustrum ibota	Ibota privet.
ovalifolium	California privet.
Liquidambar styraciflua	Sweetgum.
Magnolia acuminata	Cucumbertree.
cordata	Yellow cucumbertree.
glauca	Sweetbay.
kobus	Kobus magnolia.
liliflora	Lily magnolia.
macrophylla	Bigleaf magnolia.
soulangeana	Saucer magnolia.
stellata	Star magnolia.
tripetala	Umbrella magnolia.
Mahonia aquifolium	Oregon hollygrape.
bealei	Leatherleaf hollygrape.
Malus baccata	Siberian crab.
coronaria	Wild sweet crab.
dawsoniana	Dawson crab.
floribunda	Japanese flowering crab.
ioensis	Prairie crab.
niedzwetzkyana	Redvein crab.
sargenti	Sargent crab.
scheideckeri	Scheidecker crab.
spectabilis	Chinese flowering crab.
Myrica cerifera	Southern waxmyrtle.
Nyssa sylvatica	Tupelo.
Oxydendron arboreum	Sourwood.
Paulownia tomentosa	Royal paulownia.
Philadelphus coronarius	Sweet mockorange.
Phillyrea decora	Lanceleaf phillyrea.
Photinia villosa	Photinia.
Picea alcockiana	Alcock spruce.
canadensis	White spruce.
engelmanni	Engelmann spruce.
excelsa	Norway spruce.
omorika	Serbian spruce.
orientalis	Oriental spruce.
polita	Tigertail spruce.
pungens	Colorado spruce.
Pieris floribunda	Mountain andromeda.
japonica	Japanese andromeda.
Pinus banksiana	Jack pine.
cembra	Swiss stone pine.
densiflora	Japanese red pine.
excelsa	Himalayan pine.
flexilis	Limber pine.
montana	Swiss mountain pine.
nigra	Austrian pine.
parviflora	Japanese white pine.
ponderosa	Western yellow pine.
resinosa	Red pine.
strobus	White pine.
sylvestris	Scotch pine.
thunbergi	Japanese black pine.

Platanus orientalis	European planetree.
Prunus avium	Mazzard.
cerasifera	Myrobalan plum.
lannesiana	Hitoye cherry.
sargentii	Yama cherry.
sieboldi	Siebold cherry.
Pseudotsuga douglasi	Douglas fir.
Pyracantha coccinea	Scarlet firethorn.
Quercus palustris	Pin oak.
robur	English oak.
rubra	Common red oak.
Rhododendron carolinianum	Carolina rhododendron.
catawbiense	Catawba rhododendron.
maximum	Rosebay rhododendron.
Rhus sp	Sumac.
Sciadopitys verticillata	Umbrella-pine.
Styrax japonica	Japanese snowball.
Symphoricarpos vulgaris	Coralberry.
Syringa chinensis	Chinese lilac.
japonica	Japanese tree lilac.
vulgaris	Common lilac.
Taxodium distichum	Common baldcypress.
Taxus baccata	English yew.
canadensis	Canada yew.
cuspidata	Japanese yew.
Thuja occidentalis	American arborvitae.
orientalis	Oriental arborvitae.
standishi	Standish arborvitae.
Tilia vulgaris	Common linden.
Tsuga canadensis	Canada hemlock.
caroliniana	Carolina hemlock.
diversifolia	Japanese hemlock.
sieboldi	Siebold hemlock.
Ulmus americana	American elm.
campestris	English elm.
Viburnum carlesi	Fragrant viburnum.
cassinoides	Withe-rod viburnum.
dilatatum	Linden viburnum.
lentago	Nannyberry.
molle	Kentucky viburnum.
opulus	European cranberrybush.
prunifolium	Blackhaw.
sieboldi	Siebold viburnum.
Wisteria frutescens	American wisteria.
sinensis	Chinese wisteria.

FUMIGATION OF FRESH FRUIT TO KILL THE ADULT BEETLE

Raspberries, blackberries, blueberries, peaches, and other fruits that are harvested during the summer when the adult Japanese beetle is in flight have been known to carry this insect when packed in boxes, baskets, or crates for market. It was found that inspection was slow, laborious, often injurious to the fruit, and not always successful in detecting and removing the insects. It became necessary to develop a practical method of fumigating the different fruits to eliminate the danger of disseminating the pest in these commodities.

Experiments carried on by Osburn (*110*), in 1928 and 1929, showed that it was possible, by fumigating with carbon disulphide, to destroy the beetles in baskets of fruit without causing serious damage to the fruit. The treatment that was developed has been in use commercially since the summer of 1929, and more than 30,000 crates and baskets have been treated successfully.

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CONCENTRATION OF VAPOR REQUIRED

The concentration of carbon disulphide required to destroy the beetle in baskets of fruit was determined in a metal-lined, gas-tight fumigation chamber of 1,000 cubic feet capacity, equipped with a thermostatically controlled heating system to maintain the temperature desired, and with a "gasifier", modeled after the apparatus described by Weigel, Young, and Swenson (*159*), to vaporize the carbon disulphide. The adult beetles were exposed directly and in baskets of fruit to different dosages of carbon disulphide at different temperatures for various periods. It was found that beetles were killed as readily among the fruit as they were when exposed directly to the action of the vapor.

Temperature is the most important factor affecting the dosage of carbon disulphide necessary to destroy the beetles among fruit. It was found that the following dosages were required to kill all of the beetles among the fruit within a period of 2 hours at the different temperatures listed:

Temperature (° F.)	*Dosage (pounds per 1,000 cubic feet)*
80	10
85	10
90	7. 5
95	2. 5

No experiments were carried out with infested fruit in this chamber at temperatures of less than 75° F., because it was not possible to cool the chamber below the temperature of the surrounding atmosphere. At a temperature of 75°, a dosage of 10 pounds to 1,000 cubic feet did not destroy all the beetles. From laboratory experiments, however, it would be expected that a dosage of 15 pounds would be necessary at a temperature of 75° and 40 pounds at 70° to eliminate the infestation. It is apparent, that for commercial fumigation, the temperature of the chamber should be maintained at at least 80°.

The compactness of the material to be fumigated modifies to some extent the period of exposure required for the vapor to penetrate in insecticidal concentration. The air space in the packages of fresh fruit, when packed for shipment, varies in volume according to the size, shape, and firmness of the fruit. It was found necessary to continue the treatment for 2 hours to destroy all the beetles in baskets of raspberries, blackberries, blueberries, strawberries, and peaches, although most of the beetles were killed within 1 hour.

EFFECT OF FUMIGATION ON FRUIT

During the summer of 1929, 12 varieties of fruit, among which were blueberries (*Vaccinium* sp.) of the varieties Jersey, Grover, Rubel, and the Coville hybrid 1613–C, red currants (*Ribes* sp.), gooseberries (*Ribes* sp.), blackberries (*Rubus* sp.), variety Black Diamond, red raspberries (*Rubus* sp.), variety St. Regis, strawberries (*Fragaria* sp.), varieties Howard 17 (Premier) and Big Tom, plums (*Prunus* sp.), and peaches (*Amygdalus persica*), variety Elberta, were fumigated with carbon disulphide at a dosage of 10 pounds to 1,000 cubic feet for 2 hours at a temperature of 80° F. The fruit was obtained on the open market and treated in the original containers. After the treatment the fruits were held under observation until the effect could be determined.

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Fumigation with carbon disulphide did not appear to have any detrimental effect on the fruits. In only a few cases, immediately after treatment, was it possible to detect any taste of the fumigant in the fruit. An analysis was made of some blackberries in which the taste of carbon disulphide was detected, and it was found that there was less than 2 mg of the compound in a kilogram of the fruit. The treatment did not affect the appearance of the fruit, except that in the case of some of the blueberries a part of the bloom was removed.

The keeping quality of the treated fruit was determined by comparing the number of firm fruits in the treated groups with the number in untreated groups. With the keeping quality of the untreated fruits rated as 100, the comparative keeping qualities of the treated fruits were as shown in table 5.

TABLE 5.—*Keeping qualities of fruits fumigated with carbon disulphide compared with those of untreated fruits of each variety which were rated at 100*

Fruit	Variety	Rating
Blueberries	Grover	81
Do	Jersey	69
Do	Rubel	110
Do	1613–C	66
Raspberries	St. Regis	101
Blackberries	Black Diamond	102
Strawberries	Big Tom	92
Do	Howard 17	98
Red currants		99
Gooseberries		100
Peaches	Elberta	105
Plums		86

It is apparent that, with the possible exception of two varieties of blueberries, fumigation with carbon disulphide did not seriously impair the keeping quality of the different fruits.

TREATMENT OF GRASSLANDS WITH CARBON DISULPHIDE EMULSION

In addition to its usefulness in destroying infestations of the Japanese beetle about plants or fruits that are to be shipped outside the quarantine zone, carbon disulphide is also a valuable control material for destroying the larvae in lawns and golf greens, where the beetles find attractive breeding grounds. During summers of normal rainfall, when the grass retains a uniform green color, the infestation is likely to be generally distributed over a grass plot, but in dry summers it is confined largely to the moist portions of the lawns and to the greens on the golf courses. It has been observed by Leach et al. (*83*, *87*) that well-kept turf is capable of supporting 100 larvae of the Japanese beetle per square yard without showing evidence of injury. A further increase in the larval population will result in injury directly proportional to the number of larvae feeding on the roots. Severe damage results when the infestation reaches 1,000 larvae per square yard. When lawns or golf courses become heavily infested, it is necessary to destroy the larvae or the grass will be ruined.

Komp (*76*) and Headlee (*54*) have reported control of larvae of (*Phyllophaga*) *Lachnosterna* in grasslands by injecting carbon disulphide in holes 3 inches deep and 12 inches apart, the former using

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1 ounce of the chemical in each hole, and the latter three-fourths of an ounce. The writers found this to be effective in controlling the Japanese bettle larvae when the compound was applied at the rate of 27 g (three fourths of a fluid ounce) to a square foot in holes 12 inches apart and 1 to 2 inches deep and the surface of the ground covered with a wet tarpaulin or similar material to confine the vapor. The treatment, however, resulted in considerable injury to the grass, particularly around the points of injection. It has been found that the most satisfactory method of using carbon disulphide on infested grass is to apply it as a dilute emulsion late in the summer, when the larvae are small and feeding near the surface and the period of oviposition is practicaly completed.

It has been found that applying a dilute emulsion, containing 4.37 g of carbon disulphide per liter (4½ fluid ounces in 10 gallons), at the rate of 1 quart to a square foot of well-kept turf, destroyed 95 percent of the larvae, under favorable conditions. It is essential to keep the lawn moist for several days prior to the application of the insecticide, to keep the larvae feeding near the surface where they can be reached by the emulsion. If the surface soil is dry for several days prior to treatment, the larvae are likely to be at a depth of 2 to 4 inches below the surface at the time of treatment and may escape the action of the toxic liquid. When the treatment is applied under these unfavorable conditions, there may be sufficient larvae surviving to continue to cause appreciable injury to the roots of the grass.

An emulsion for treating lawns was prepared by diluting 1 part of a 70-percent stock emulsion with 200 parts, by volume, of water. If it is desired to use a weaker stock emulsion proportionately more emulsion should be mixed with the water to obtain the required concentration of carbon disulphide. The volume of dilute emulsion to be prepared at one time will depend upon the area of turf to be treated and the facilities for mixing that are available. Instead of preparing the dilute emulsion in a tank, the stock emulsion may be diluted with water during the process of application by means of a special mixer that has been developed at the laboratory (*85*).

It is important that the emulsion be applied to grass in a systematic manner in order to assure a uniform distribution over the surface. The size of the plot that can be covered by a definite volume of the dilute emulsion should be definitely determined and the area marked by lines of coarse twine or other suitable material. The liquid may be applied to small areas by means of a watering pot, but larger areas are treated more conveniently by means of a special nozzle from which the liquid flows naturally in a fanlike stream, as shown in figure 40. The operator should begin to apply the liquid at one end of the plot and move slowly over the turf, taking care to cover the ground with a layer of liquid, to avoid puddling or excessive run-off, and to leave no untreated areas. The nozzle should be held within a few inches of the ground during this operation to avoid as much as possible the loss of the toxic gas from the liquid. It has been found that 1 quart of liquid cannot be applied to a square foot of turf at one time without excessive run-off. It is best to apply the liquid until the danger of run-off or puddling is imminent and then allow it to soak into the ground before applying the remainder of the allotted quantity. If the dilute emulsion remains on the surface for a considerable

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period, particularly on a hot day, it is likely to injure the grass. On the other hand, the penetration of the liquid with several light applications several hours apart may not be sufficient to destroy the larvae.

Various grasses and clovers, including redtop, low speargrass, fescue, German bent, and creeping bent, have been treated during the course of the experimental work and have withstood the treatment when in a vigorous condition, but were injured when treated while in a weakened state. The only general injury encountered in treating vigorous turf occurred in hot weather. Some injury usually appears in low spots where an excessive quantity of the liquid collects. If the treated areas are watered daily after the application of the insecticide, the grass generally returns to a normal green within a few days, and the treatment usually results in a pronounced stimulation of growth, apparent a week or 10 days later.

FIGURE 40.—Applying carbon disulphide emulsion to a lawn with a hose and special nozzle. The emulsion is mixed with water from a hydrant in a definite proportion by a mixing device (left center) developed at the Moorestown laboratory.

This treatment was also found by Lipp (*91*) to be effective against the larvae of the green June beetle (*Cotinis nitida* L.) in lawns. Zappe and Garman (*166*) and Johnson (*72*, *73*) found that this treatment practically eliminated infestations of larvae of the oriental beetle (*Anomala orientalis* Waterh.) in lawns without causing serious damage to the grass. It was estimated that 98 percent of the larvae were destroyed and that the injury to grass due to the treatment did not exceed 1.5 percent, while the damage to shrubs was negligible. Thomas (*142*) applied 2 quarts of emulsified carbon disulphide to a square foot of grass on golf courses in the southeastern part of the United States and obtained 95 percent control of the changa (*Scapteriscus vicinus* Scudd.) for about 1 month, after which reinfestation began.

The treatment of grassland with carbon disulphide will not prevent reinfestation by any of these insects. It must be considered, therefore, as a satisfactory procedure for temporarily controlling the soil-inhabiting pests in grasslands.

RECOMMENDATIONS FOR DISINFESTING NURSERY STOCK, SOIL, AND FRUITS TO MEET QUARANTINE REQUIREMENTS

Recommendations [5] have been prepared for the use of carbon disulphide for the treatment of nursery stock, fruit, plant products and materials, soil, sand, peat, compost, and manure, to eliminate the different stages of the Japanese beetle. Material treated according to the procedures outlined may be certified for shipment to points outside the quarantined zone as free of infestation within the requirements of Quarantine No. 48 (*150*). A summary of these recommendations has been published by the writers (*32*). It should be understood that these treatments have not been tried on all plants or under all of the varied conditions. The aim of these treatments has been the destruction of the insects, and no guarantee can be given that no injury will be caused to the different plants and products. A rather brief abstract of the accepted recommendations for the use of carbon disulphide is given in the following sections.

DISINFESTATION OF SOIL IN THE ABSENCE OF PLANTS

FUMIGATION OF POTTING SOIL

Soil of any type may be fumigated, provided it is friable and thrown loosely into a tight box or bin. The temperature should be at least 45° F. when the treatment is applied and must not fall below 40° during the period of treatment. Carbon disulphide, of the commercial, U. S. P., or C. P. grades, should be injected at the rate of 1 pound to a cubic yard of soil in such a manner that the chemical is distributed evenly throughout the soil. The box or bin must be sealed after the fumigant has been applied, and left undisturbed for at least 48 hours. The treated soil must be stored so as to prevent reinfestation.

FUMIGATION OF PLOTS OF SOIL

Carbon disulphide, of the above-mentioned grades, should be used at the rate of 6 pounds to 100 square feet of soil surface for the disinfestation of plots of soil. The soil should be friable at the time of treatment. The chemical must be applied in holes 12 inches apart and 1 to 2 inches deep so that it is distributed uniformly throughout the upper 6 inches of soil. The temperature of the soil, at a depth of 6 inches, should be at least 45° F. when the treatment is applied and must not fall below 40° while the fumigation is in progress. The plot of treated soil should be covered with a tarpaulin or other airproof cover for at least 48 hours after treatment. The ideal weather condition for treatment is a warm, humid atmosphere without wind. The treatment must not be applied when adult beetles are present, except in the case of plots protected from the beetles.

[5] U. S. DEPARTMENT OF AGRICULTURE, PLANT QUARANTINE AND CONTROL ADMINISTRATION. INSTRUCTIONS TO INSPECTORS ON THE DISINFECTION OF NURSERY PRODUCTS FOR THE JAPANESE AND ASIATIC BEETLES. Mimeographed Pubs. 224, 265. 1929, 1930.

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DISINFESTATION OF SOIL ABOUT THE ROOTS OF PLANTS

TREATMENT WITH CARBON DISULPHIDE EMULSION IN THE FIELD

A stock emulsion, containing not less than 49 percent or more than 51 percent carbon disulphide by volume, prepared according to formula 10 (p. 12), should be used in preparing the dilute emulsion for application to plants. The treating solution should be applied at the rate of 2.5 gallons per square foot of soil surface.

The proportion of carbon disulphide in the treating solution required to kill the insect varies with the temperature of the soil as follows:

Minimum soil temperature 6 inches below the surface:	*Stock emulsion per 10 gallons of water, in cubic centimeetrs*
40°–50° F	68
50°–60° F	57
60°–70° F	45

For the treatment of soil about the roots of plants, the collar, which is placed around the plant to form a basin, should be somewhat larger than the ball of earth that will be removed when the plant is dug. These collars should be of 24-gage galvanized iron and should be 10 inches high and set 3 inches deep in the soil about the plant. Where the diameter of the ball to be dug is 12 inches, or less, the collar should be 18 inches in diameter. Where the diameter of the ball to be dug is 36 inches, the collar should be 48 inches in diameter. Where it is more convenient, square collars may be substituted for the round collars. This procedure affords an ample safety zone to prevent the movement of larvae from adjacent untreated soil until the plant is dug.

The temperature of the soil must remain above 40° F. at a depth of 6 inches in the ground during the entire period of treatment. In treating a plant, all weeds should be removed from around the plant and the low hanging branches tied so that they will not come into contact with the solution. Before treating the plants, an examination of the soil should be made by digging to a depth of at least 12 inches outside the collar to determine whether the type of soil and the conditions are favorable for proper treatment. The soil should be leveled and the emulsion poured into the collar and allowed to remain undisturbed for 48 hours. A record should be made of the time and the uniformity of penetration of the emulsion on each plant treated. If the emulsion disappears from the surface in less than 10 minutes, or requires more than 5 hours to be absorbed by the soil, the treatment may not be successful. The plant should be dug 2 to 5 days after it is treated, care being taken to dig within the treated area so as to prevent any untreated soil from being taken up with the plant. At the time the plant is dug, a careful examination should be made of the outside of the soil ball and of the surrounding treated soil, and any living larvae found collected and a record made of their condition 3 days after digging. If the treatment has been successful, the larvae will be dead at the end of that time.

TREATMENT BY SUBMERGING ROOTS IN CARBON DISULPHIDE EMULSION

The stock carbon disulphide emulsion, formula 10, recommended previously, should be diluted with water, just before using, at the rate of 45 cc of emulsion to 10 gallons of water. The plants should be prepared for treatment by removing the loose soil and pruning

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the roots. The roots should be submerged in the emulsion for 24 hours at a temperature of 70° F. If the temperature falls below 65°, the treatment may not be successful in killing the insects, and if it rises above 70°, the plants may be injured. The emulsion is least injurious when the plants are dormant, and it is recommended that the treatment be applied only during the dormant period of the variety to be disinfested. The treatment cannot be depended upon to be effective when the soil about the roots is wet or very compact, or when the diameter of the mass is more than 6 inches.

FUMIGATION OF BLACKBERRIES, DEWBERRIES, AND RASPBERRIES

Crates of blackberries and dewberries should be fumigated with carbon disulphide in a tight room at a temperature of 80° F., or above, for a period of 2 hours. The chemical, of the commercial, U. S. P., or C. P. grades, should be vaporized by being in contact with a copper coil through which hot water is circulated, a dosage of 1 pound being used to 100 cubic feet of space in the room, including the space occupied by the berries. The water in the copper coil should be at a temperature of at least 148° *and must not exceed 180°*. Fans should be provided to keep the air and gas mixture in circulation.

SUMMARY

Carbon disulphide is one of the most effective fumigants for destroying the different stages of the Japanese beetle. The concentration of vapor required varies with the stage of the insect and with the temperature and the period of exposure. The commercial grade of the chemical was equally as effective as the chemically pure grade for insecticidal purposes. Emulsification of carbon disulphide reduced the insecticidal value about one-half. The type and the concentration of the emulsifier modified to some extent the insecticidal value of the dilute emulsions.

The treatment of soil with carbon disulphide prior to planting appears to have a beneficial effect on the subsequent growth of the plants, but the application of liquid carbon disulphide, or heavy concentrations of the vapor or emulsion, to the plant roots causes severe injury or death. When the concentrations of vapor or emulsions have been carefully controlled, however, successful treatments of soil about the roots of some growing plants have been made without causing serious damage.

Soil to be used for potting plants can be fumigated with carbon disulphide to destroy the immature stages of the beetle. The use of 1 pound to a cubic yard of soil has been found necessary to assure the destruction of the insect at a temperature of 45° F. within a period of 48 hours. Ground in the commercial nurseries that is to be used for heeling in plants or plunging potted plants can be freed of infestation by injecting carbon disulphide at the rate of 6 pounds to 100 square feet when the temperature of the soil is above 45° F. and the soil is in condition to permit the diffusion of the vapor.

It was found that sufficient carbon disulphide to destroy the insect could not be injected into the soil about the roots of *Azalea hinodegiri* and *Cibotium shiedei* in pots or about the roots of *Picea*

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excelsa, Thuja occidentalis, or *Tsuga canadensis* in the field without causing severe injury or the death of the plants.

Soil balls about the roots of *Azalea indica* and *Hydrangea opuloides* were fumigated with an insecticidal concentration of carbon disulphide vapor in a closed chamber by inverting the plants and submerging the aerial portions in water during the treatment. Successful insecticidal action is limited to some extent by the moisture content of the soil.

Several varieties of herbaceous and deciduous plants were treated successfully by submerging the roots in a dip of dilute carbon disulphide emulsion, but the insecticidal concentrations were injurious to evergreens.

The treatment of potted plants by pouring a dilute emulsion onto the soil was successful in destroying the immature stages of the beetle without damaging the plants, but the procedure was too slow and expensive to be practical in commercial nurseries.

The application of carbon disulphide emulsion to the soil about the roots of nursery plants in the field has destroyed infestations of the insect without causing serious injury to evergreen and deciduous plants. The various species of ornamental plants that have been successfully treated with emulsified carbon disulphide are listed.

Blackberries, raspberries, and other fruits have been fumigated with an insecticidal concentration of carbon disulphide vapor without causing damage to the fruit.

Treatment of infested grasslands with dilute carbon disulphide emulsion controlled the larvae under favorable conditions without causing serious damage to the grass.

An abstract is given of the approved recommendations on the basis of which nursery stock and crated berries may be certified as free of infestation and be permitted shipment outside of the quarantine zone.

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UNITED STATES DEPARTMENT OF AGRICULTURE
WASHINGTON, D.C.

APANTELES SOLITARIUS (RATZEBURG), AN INTRODUCED BRACONID PARASITE OF THE SATIN MOTH

By D. L. PARKER,[1] *junior entomologist, Division of Forest Insects, Bureau of Entomology and Plant Quarantine*

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INTRODUCTION

Apanteles solitarius (Ratzeburg)[2] is a solitary, internal parasite of the satin moth (*Stilpnotia salicis* L.). The satin moth, a pest of poplar and willow trees, was first discovered in the United States in 1920 just north of Boston, Mass. About a month later it was found in British Columbia, and in 1922 in the State of Washington. Since 1920 this insect has spread rapidly in the New England States, and a portion of this region is now under quarantine on account of it (fig. 1). The staff of the Budapest, Hungary, laboratory of the Bureau of Entomology, United States Department of Agriculture, made observations at areas in central Europe infested with the satin moth with the intention of obtaining for liberation in New England such primary parasites as attack it there but were not established in the United States. *A. solitarius* seemed to be generally distributed throughout central Europe wherever the satin moth was observed, and apparently was a valuable factor in its

[1] The writer is indebted to C. W. Collins, in charge of the Bureau of Entomology and Plant Quarantine laboratory at Melrose Highlands, Mass., for his cooperation in these studies. Acknowledgment is made to those members of the staff who worked on these experiments, especially C. F. W. Muesebeck and P. B. Dowden, who supervised these activities at different periods. Mr. Muesebeck also determined the adults that were reared during the crossbreeding experiments.

[2] Order Hymenoptera, superfamily Ichneumonoidea, family Braconidae.

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control (*1, pp. 8–9*).[3] The first shipment of parasite cocoons to this country was made in the summer of 1927, primarily as an experiment to determine the advisability of sending the parasite in the cocoon stage. Upon receipt of the cocoons at the Melrose Highlands, Mass.,

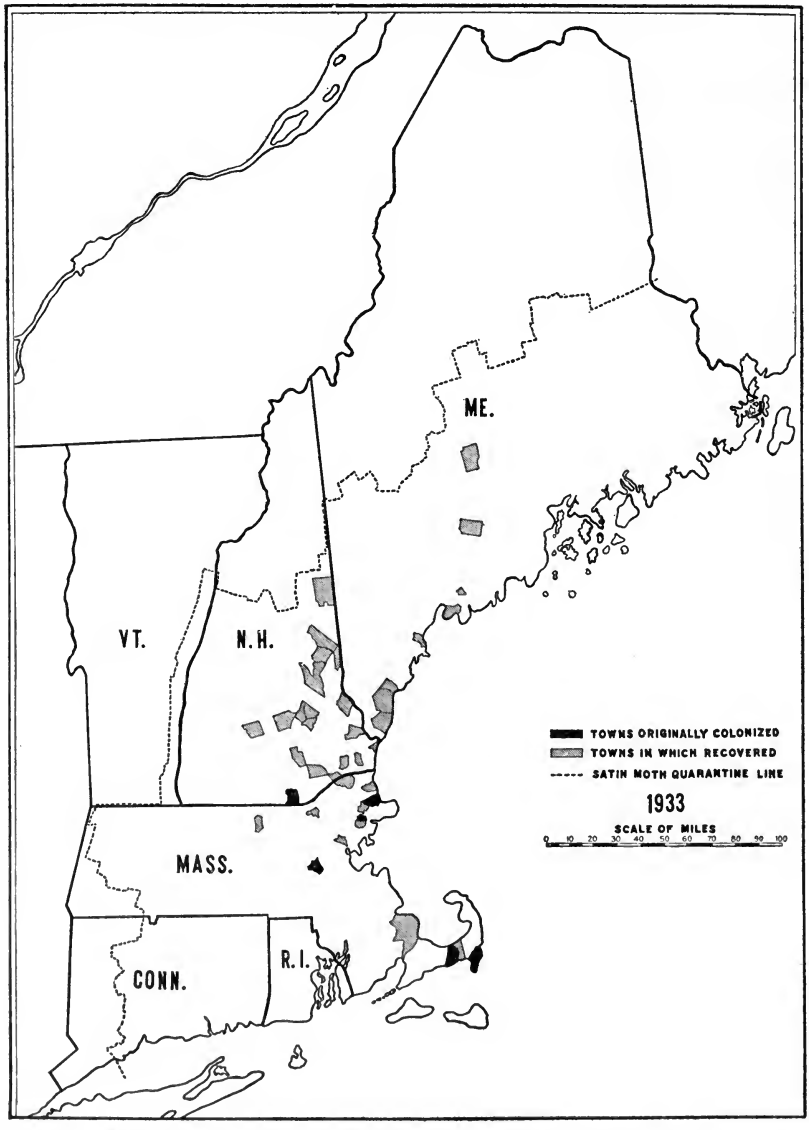

FIGURE 1.—Map showing area in New England quarantined in 1933 against the satin moth and the present known distribution of *Apantcles solitarius*.

laboratory, studies were begun on the biology of this parasite and its effectiveness in controlling the satin moth. The information obtained is presented in this bulletin.

[3] Reference is made by number (italic) to Literature Cited, p. 17.

IMPORTATION AND COLONIZATION

In the shipment of *Apanteles solitarius* received in 1927 there were 105 cocoons. A total of 36 male and 19 female adults issued from these cocoons. The species became established quickly, and there were no additional shipments of *solitarius* material until 1932, when 542 cocoons were included in shipments of other parasites. All the adults colonized prior to 1932 were bred from the females received in the original shipment. Since 1932 very few cocoons have been received.

From 1927 to 1932 adults of this species were liberated in 5 towns in Massachusetts and 1 town in New Hampshire, and one lot of adults was shipped to Kent, Wash. With the exception of one colony in Massachusetts, which was placed in an area infested with the white-marked tussock moth (*Hemerocampa leucostigma* S. and A.), all the liberations were made in localities infested with the satin moth. Adults were liberated at two periods in the life cycle of the satin moth, at the time the larvae were feeding after leaving their hibernacula and when the larvae were hatching from the eggs during the summer.

Colonization was also effected by the liberation of first- and second-instar larvae of the satin moth that had been parasitized in the laboratory. Parasitized larvae were liberated in 2 towns in Massachusetts, in 1 of which adults were also liberated. It was believed that, by placing the parasitized larvae in the field just prior to hibernation, most of the parasites would issue at about the same time and be concentrated in the infested area, and that this would lessen the work of rearing the adult parasites.

This method can be used to colonize the species, but it is doubtful if it is so satisfactory as the liberation of adults. Observations made at one infested area where parasitized larvae had been liberated indicated that very few of the larvae had survived the winter. The base of one limb of a willow tree upon which parasitized larvae had been placed was treated with a sticky tree-banding material to force the larvae to remain on this small section of the tree while feeding, and also to hibernate there instead of on the trunk. When the limb was examined in the spring, few larvae were present.

In 1933 the Canadian Department of Agriculture sent two representatives to the Melrose Highlands laboratory to obtain *Apanteles solitarius* material for colonization in areas infested with the satin moth in Canada. These men, with assistants, collected the parasite cocoons, held them in a cool place, and transported them to the laboratory in Canada, where the adults were allowed to issue. These adults were then sent to various points in Canada for liberation. According to subsequent correspondence from Canada, the species has been recovered from Sussex, Moncton, and Sackville in New Brunswick, and from Amherst in Nova Scotia. In British Columbia the species has been recovered over a fairly large area in the Fraser River Valley around Nicomen, the liberation point.

DISTRIBUTION

In order to study the occurrence and spread of *Apanteles solitarius*, hibernating satin moth larvae were collected in towns over an area

extending from Rhode Island to Maine through Massachusetts and New Hampshire.

The year following the first liberations the species was recovered in four localities in Massachusetts, New Hampshire, and Maine. The parasite spread rather rapidly. One year after it was liberated at Nashua, N. H., it was recovered at Manchester, N. H., about 15 miles away. The second year after liberation it appeared in collections from 8 towns, 4 in Massachusetts and 4 in New Hampshire. The parasite has continued to spread and is now apparently distributed throughout the area in New England that is infested by the satin moth. The towns in which recovery collections have shown establishment of this parasite are shown on the map in figure 1, but without doubt the parasite is present in many other towns.

HOST RELATIONS

Apanteles solitarius is capable of reproducing on several lepidopterous hosts other than the satin moth. At the laboratory many adults were reared from larvae of the gypsy moth (*Porthetria dispar* L.). This host was used in the rearing experiments because it was easier to collect the gypsy moth eggs in the spring and rear the larvae for parasitization than to collect small satin moth larvae in the field. *A. solitarius* has also been reared successfully on the rusty tussock moth (*Notolophus antiqua* L.), the white-marked tussock moth (*Hemerocampa leucostigma* S. and A.), and the brown-tail moth (*Nygmia phaeorrhoea* Don.). Attempts were made to overwinter the species in the small larvae of *N. phaeorrhoea*, *Euphydryas phaëton* Drury, *Basilarchia archippus* Cramer, and *Olene* sp., but without success.

There have been no field recoveries of *Apanteles solitarius* from these hosts, but it would be surprising if it did not attack gypsy moth larvae when they are present in the same locality as the satin moth.

METHOD OF LABORATORY BREEDING

It was comparatively easy to breed *Apanteles solitarius* in the laboratory. The method that appeared to be the most satisfactory and efficient for bringing about reproduction of the species for liberation purposes will be described.

Parasitization of host larvae was accomplished in glass vials (8 by 2 inches). From 3 to 5 mated females were placed in each vial and a larva was introduced on a fine camel's-hair brush. As soon as a female had oviposited within the larva, it was removed and another one was introduced. With 35 to 50 mated females, one man could subject 700 to 1,000 larvae to parasitization in a day. The parasitized larvae were placed in lots of 200 in paraffined paper trays the sides of which were banded with a sticky tree-banding material to prevent the escape of the larvae. The larvae in the trays were fed with oak foliage until the cocoons of the parasite were formed, and then the cocoons were removed to glass vials (4 by 1 inches) and kept there until the adults issued. A number of adults of each sex were placed in cages and held for later mating. These cages (9½ by 6⅜ by 4½ inches) had sliding glass tops and a hole at one end through

which a sponge saturated with a solution of honey and water could be introduced. The mated females used in reproduction experiments were kept in glass vials (8 by 2 inches) in a dark, cool place when they were not being used for parasitization of larvae. The adults that were colonized were held in wooden boxes or small cloth cages in a cool place until time of liberation.

THE ADULT

DISTINGUISHING CHARACTERS

Apanteles solitarius (fig. 2) was first described by Ratzeburg (*7, p. 73*) as *Microgaster solitarius* in 1844. This species is closely re-

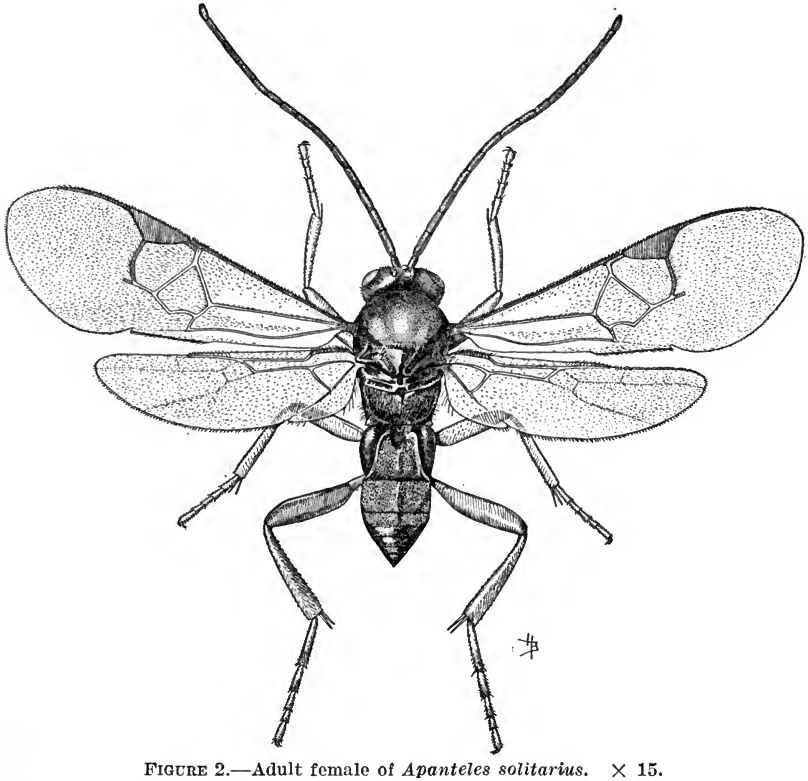

FIGURE 2.—Adult female of *Apanteles solitarius*. × 15.

lated to *A. melanoscelus* (Ratz.), and there has been some confusion regarding the two species, but the differences are sufficiently marked to permit their separation. A redescription of *melanoscelus* was presented by Crossman (*3, p. 3*) in 1922. The main difference between *solitarius* and *melanoscelus* is in the sculpture of the abdominal tergites. In *solitarius* the sculpture of the third tergite is usually more extensive and stronger, at least medially. In *solitarius* the second tergite is usually more extensively sculptured; in *melanoscelus* the sides of the second tergite, especially apically, are mostly smooth.

MATING

The chief difficulty encountered in breeding *Apanteles solitarius* was in getting the sexes to mate. Many attempts were made to induce mating in cages and vials of various types and sizes under varied conditions of light and temperature with adults of different ages. The conditions most suitable for normal mating seemed to be a temperature of 65° to 70° F. and a somewhat subdued light. Even under these conditions it was a long and tedious task to obtain 10 or 15 mated females. Finally a procedure was devised by which it was possible to obtain enough mated females for propagation. The virgin females were starved for 8 to 10 hours and then about 10 to 15 were placed in a cage with 25 males that had had access to food. A wooden-frame cage, 9½ by 6⅜ by 4½ inches, covered with cloth except for a sliding glass front, seemed more suitable than larger cages. A little honey-and-water solution was spread on the cloth back of the mating cage, and the females, being very hungry, fed there eagerly, which allowed the males to mate with them successfully. The possible effect of such mating was unknown, but it proved successful when judged by the sex ratio of the adults reared in the experiment. When such a method is used, it is important to keep the females in a dark place while they are being starved, for too much activity during this period of 8 to 10 hours will exhaust them and many will die.

The position taken during mating is normal to species of *Apanteles*, and the act is completed in less than a minute.

OVIPOSITION

The adults of *Apanteles solitarius* are ready to oviposit within a few hours after they issue from the cocoons. The act of oviposition is not one of slow and studied attack, but rather a nervous thrust. When the female senses the presence of a suitable host larva, she approaches it rapidly and very quickly inserts the ovipositor with a thrust and immediately leaves the larva. The female may oviposit in any part of the caterpillar, and eggs deposited in any part of the body will develop.

REPRODUCTIVE CAPACITY

In order to ascertain the reproductive capacity of this species, it was decided to isolate 5 females and allow them to attack a few larvae each day. From 5 to 10 larvae were placed with each female during the day and removed late the same day. They were dissected the following day, for it was found that the eggs of the parasite enlarged, and were therefore more readily seen, after 24 hours.

The females issued on June 13 and began to oviposit June 14. They oviposited every day for at least 13 days, and 1 female oviposited for 20 days. The number of eggs deposited ranged from 311 to 516, with an average of 402. The largest number of eggs laid by 1 female in 1 day was 53.

PARTHENOGENESIS

Unfertilized females of *Apanteles solitarius*, like many other parasitic Hymenoptera, deposit eggs that develop to male adults.

LONGEVITY

No experiments were conducted with the sole purpose of determining the length of life of adults of *Apanteles solitarius*. During the work on reproduction it was determined that the adults would live only a short time without food. Adults that had no food from late afternoon through the night were dead the next morning. Adults fed a solution of honey and water and held in a dark, cool room lived fairly long. In one lot of adults the peak of issuance occurred from May 6 to 9, and on May 31, 1,150 adults were alive out of an original 1,407. Another lot of 2,509 adults that issued from June 14 to 27, with the peak of issuance from June 17 to 18, was reduced in numbers to 1,389 on July 21, nearly a month after the last adult issued. Some of the deaths in the latter lot may be attributed to escaping gas in one of the insectaries. It is safe to say that the average length of life of these adults is from 3 to 4 weeks, and that the females live longer than the males.

THE EGG

The egg of *Apanteles solitarius* (fig. 3) at the time of deposition measures 0.28 to 0.53 mm in length and 0.06 mm in width at the widest part. It increases in size very rapidly in the dissecting fluid, and should therefore be measured as soon as possible after deposition. It is almost transparent, rounded at the cephalic end, enlarged medially, and narrowed posteriorly to a small petiole. The surface is smooth.

FIGURE 3.—Egg of *Apanteles solitarius*. × 245.

The eggs of this species develop rather rapidly and change greatly in size and shape. At the end of 48 hours some eggs measured 0.52 to 0.55 mm in length and 0.22 to 0.24 mm in width and were much smaller near the cephalic end. At this time the embryo was plainly seen lying in a slightly curved position.

The incubation period varies according to the temperature. In warm weather, at the time of reproduction experiments with the second generation, hatching was observed 69 hours after oviposition. The average time required for hatching earlier in the season, in May, was about 1 week, and in June or later it was 3 or 4 days.

THE FIRST-INSTAR LARVA

The first-instar larva of *Apanteles solitarius* (fig. 4) averages 0.58 mm in length and 0.18 mm in width at the time of hatching. Immediately after hatching, the larva may be found floating free in any part of the body cavity, but it gradually works its way to the posterior half of the body, where it remains the rest of its larval life. The newly hatched larva has a nearly transparent body, which tapers slightly from the large squarish head to the caudal end, which bears the caudal horn and bladderlike dorsal anal vesicle. This anal

vesicle may not be prominent immediately after hatching, but it is soon evaginated. The newly hatched larva consists of the head, 3 thoracic segments, and 8 distinct abdominal segments. The last segment really consists of 3 undifferentiated segments, which become distinguishable later in the development of the first instar. On the dorsum of the second and third thoracic segments and on the first 8 abdominal segments there are irregular rows of rather stout but colorless spines. There are usually 2 spines on the last 2 thoracic segments, and they increase in number on each abdominal segment toward the caudal segments, and there is an unbroken row of spines across the dorsum of the eighth abdominal segment. These spines are not figured in the drawing (fig. 4), because the larva is drawn as viewed ventrally.

The head of a first-instar larva, at the time of hatching, is about twice the width of the body. When the head is viewed laterally, the mouth opening is situated somewhat ventrally and the two labral processes extend downward over the mouth opening. When it is viewed ventrally, the mandibles (fig. 5, *A*) can be seen. They are comma shaped, sharply pointed, and measure 0.075 to 0.086 mm in length, or an average of 0.79 mm.

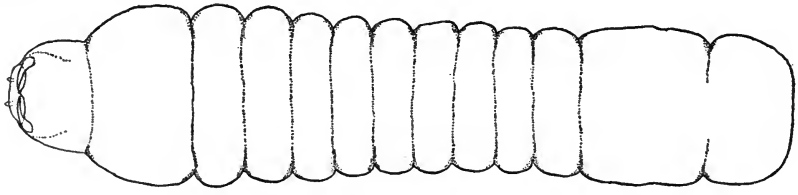

FIGURE 4.—First-instar larva (nearly full grown) of *Apanteles solitarius*, viewed ventrally. × 72.

Near the end of the first instar the appearance of the larva is greatly changed (fig. 4). The head is now small in comparison with the body, which is greatly enlarged from feeding, the anal vesicle is very large, and the caudal horn appears very small beneath the anal vesicle. There is still no visible tracheal system.

THE SECOND-INSTAR LARVA

The second-instar larva [4] differs considerably from the first. Its length increases from about 2 mm at the beginning to about 5 mm at the end of the instar. The body tapers from the large anal vesicle toward the head. The head has no apparent sclerotization, and only in the latter part of the instar is it possible to see the mandibles. The mandibles (fig. 5, *B*) are colorless, and careful adjustment of light is necessary to see them with a compound microscope. The base of the mandible is very broad, tapering to the blade, which has a bidentate tip. The mandible measures 0.07 to 0.08 mm in total length, and the blade is roughly one-half the total length. The labium and maxillae appear as fleshy lobes.

There are no open spiracles in the second instar, although the tracheal trunks can be seen during the latter part of the instar.

[4] Some authorities believe that species of *Apanteles* have more than three instars and that descriptions of the second instar include more than one instar.

THE THIRD-INSTAR LARVA

The *Apanteles* larva usually molts into the last instar just as it leaves the host and carries the anterior part of the exuvia partly out of the host as it leaves. The last-instar mandibles (fig. 5, *C*) are visible just before the molt. The exuvia can almost always be found projecting from the opening through which the larva has issued. The anal vesicle is retracted at the time of issuance from the host. The spinning of the cocoon starts immediately. Before issuing from the host the larva measures 6 to 7 mm in length, but after it has spun its cocoon it contracts to 3 to 4 mm.

During the early part of the last instar the shape of the larva greatly resembles that of the second instar, but just before issuance it assumes a shorter and plumper appearance, is tapered anteriorly, and bears fleshy lobes laterally on the first 8 abdominal segments. (Fig. 6.) The surface of the skin is minutely pebbled, and each of the first 12 segments of the body bears a ring of rather stout, sharp spines. The larva bears 8 pairs of open spiracles, 1 pair on the mesothoracic segment, and 1 pair on each of the first 7 abdominal segments.

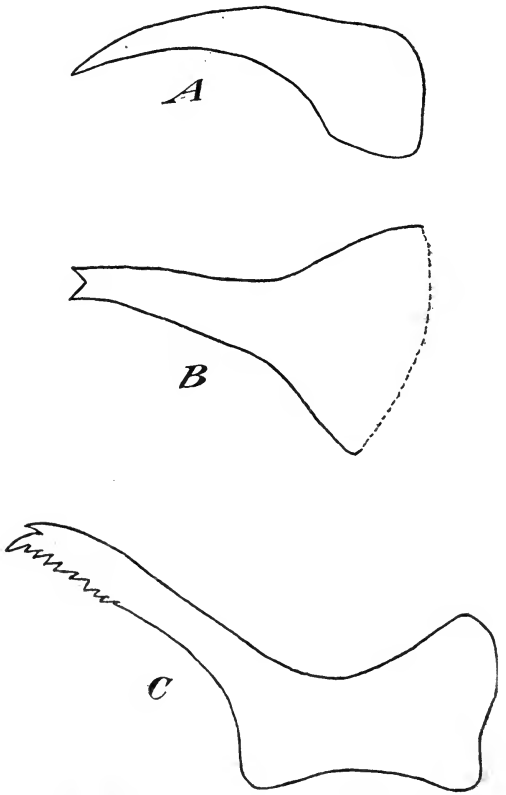

FIGURE 5.—Mandibles of larva of *Apanteles solitarius*: *A*, Of first-instar larva; *B*, of second-instar larva; *C*, of third-instar larva. × 590.

The head (fig. 7) presents a very different appearance from that of the previous instar. The buccal armature[5] is well sclerotized and mostly well defined. The labiostipital sclerome (*las*) encloses the labium (*la*) in a well-defined sclerotized border. The maxillary sclerome (*mas*) extends laterally and posteriorly from the side of the labiostipital sclerome toward the base of the hypostoma (*hy*). The hypostoma extends from the posterior part of the head at the base of the postocciput anteriorly toward the mouth opening. Beyond the junction of the hypostoma and the stipital sclerome (*sts*)

[5] The terminology used in the description of the larval head is that used by Vance and Smith in their paper on the larval head of parasitic Hymenoptera (8).

the hypostoma becomes rather indistinct, the pleurostoma is scarcely indicated, and the epistoma is not apparent. The ligular sclerome (*lis*) is faintly seen ventrad of the silk duct (*sdo*).

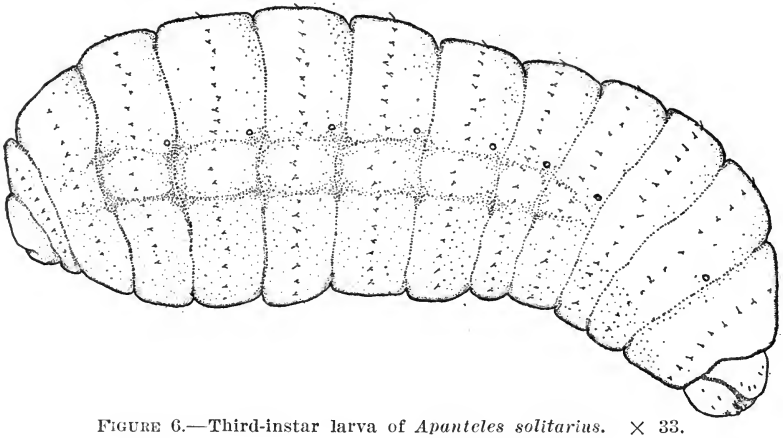

FIGURE 6.—Third-instar larva of *Apanteles solitarius*. × 33.

Dorsally above the mouth opening, situated on the labrum (*lm*), are 2 brownish pigmented areas, each enclosing 3 light-colored areas which may be sensory in function. Above these are 2 irregular

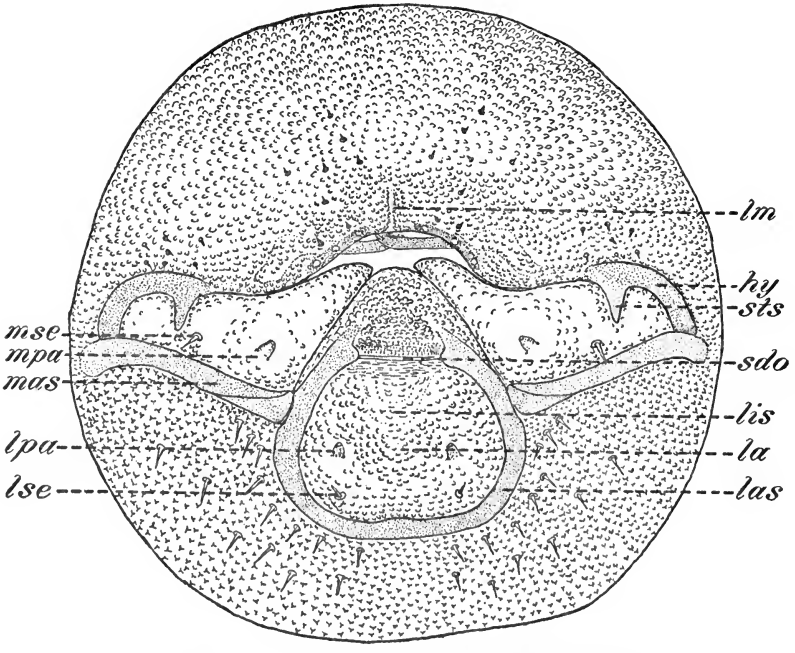

FIGURE 7.—Head of third-instar larva of *Apanteles solitarius*. × 200.

groups of spines, and laterally situated above the hypostoma there are other spines. The spines in these groups vary in number on different specimens, and even on the same individual the number

on one side of the head may differ from the number on the other side. The raised fleshy maxillae bear rudimentary maxillary palpi (*mpa*) and setae (*mse*). The labium bears 2 rudimentary palpi (*lpa*) and 2 setae (*lse*).

The labium, the maxillae, and the remaining dorsal region of the head are covered with minute papillae which give this surface a pebbled appearance. The remainder of the head ventrad of the labiostipital sclerome and the maxillary scleromes is covered with minute spines. There is a group of large spines in this area, varying in number and apparently not arranged in a definite pattern.

The mandible of the third-instar larva of *Apanteles solitarius* (fig. 5, *C*) has a rather broad base and a slender, elongate shank terminating in two teeth and bearing several rather stout teeth beneath. These mandibles measure 0.12 mm in length.

PREPUPA AND PUPA

The hibernating larvae of *Apanteles solitarius* within a cocoon remains throughout the winter as a prepupal larva, pupating late in April.

Within the cocoon that produces an adult the same season the following changes occur. In about 2 days after completing its cocoon, the larva pupates and casts its larval skin, which is found at the posterior end of the cocoon with the previously voided meconium. The pupa is white at first, but it gradually becomes black. The pupal skin is cast and the adult escapes after cutting the circular cap at the end of the cocoon.

CROSSBREEDING EXPERIMENTS

Because of the morphological similarity between *Apanteles solitarius* and *A. melanoscelus*, several crossbreeding experiments were conducted. Females of each species were mated with males of the other, and the resulting progeny were carried through two generations. The adults reared in these experiments were classified by C. F. W. Muesebeck, of the Division of Insect Identification, as follows: (1) Typically *A. melanoscelus*, (2) typically *A. solitarius*, (3) indeterminable.

The results have been summarized in table 1. It will be seen that the F_1 generation in both cases tended to resemble the female parent, and that this tendency was stronger in the F_2 generation. The F_1 females used in producing the F_2 generation were all mated. Apparently these species, when crossed, tend to remain as distinct species instead of converging and producing a blend of the characters. One would expect that, if these species should crossbreed in nature, the results would be similar and the identity of neither species would be lost.

TABLE 1.—*Classification of adults reared in crossbreeding experiments between Apanteles melanoscelus and A. solitarius*

Parents	Number of individuals reared in—					
	F_1 generation			F_2 generation		
	A. melanoscelus	*A. solitarius*	Indeterminable	*A. melanoscelus*	*A. solitarius*	Indeterminable
Female *A. melanoscelus* × male *A. solitarius*	124	41	61	150	24	58
Female *A. solitarius* × male *A. melanoscelus*	33	120	50	28	207	68

SEASONAL HISTORY

The seasonal history of *Apanteles solitarius* is somewhat involved, because the species may pass the winter in either of two forms. It may overwinter as a prepupal larva in its cocoon or as a first-instar larva within the host.

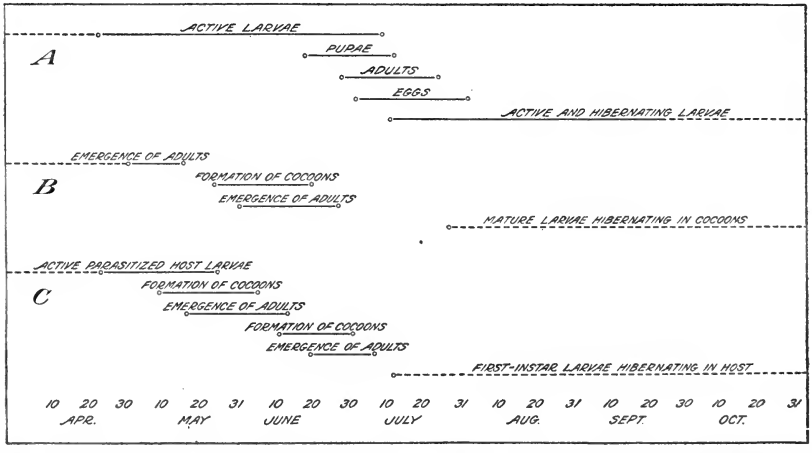

FIGURE 8.—Chart representing seasonal histories of: *A*, Satin moth; *B*, *Apanteles solitarius* overwintering in cocoon; *C*, *A. solitarius* overwintering as first-instar larva within satin moth larva.

The seasonal histories of the two hibernating forms of *Apanteles solitarius* and also that of the host are portrayed in figure 8. The information concerning the seasonal history of the host was taken from that given by Burgess and Crossman (*2*, *pp. 7–11*). The seasonal history of the parasite was compiled from laboratory rearing records and applied to the average conditions that might reasonably be expected in the field. The life of the adults might be longer or shorter than that encountered in the laboratory, and the period represented on the charts is a reasonable expectation of the length of life in the field.

The larvae of the satin moth begin to leave their hibernacula late in April, and this exodus continues until the latter part of May (fig. 8, *A*). The peak of emergence is early in May, and active growing larvae are present in the field until early in July. Pupation

starts during the last half of June and adults appear about the last of June, with the peak of emergence in July. By the first of August egg laying is practically over. The eggs hatch in about 12 to 15 days, and the larvae feed during two instars and molt into the third instar in the hibernacula.

The *Apanteles solitarius* adults that issue from cocoons formed the previous fall appear during the first part of May, the majority during the first week (fig. 8, *B*). These adults attack the larvae that are coming out of hibernation, and cocoons are formed at this time of year in about 23 to 28 days after egg deposition and the resulting adults issue from 7 to 10 days later. Some of the adults of this first summer generation live until the *Stilpnotia salicis* eggs hatch and then attack the first-instar larvae. Some of the *A. solitarius* larvae within these parasitized hosts do not develop beyond the first instar and pass the winter in this instar, resuming activity and growth when the host larvae begin feeding in the spring. Other parasite larvae complete their growth, issue, and spin cocoons, and some of these cocoons produce adults the same season while others do not until the following spring.

The parasite larvae that remain within the host during the winter resume their activity when the host larvae commence their spring feeding (fig. 8, *C*). They usually issue and form their cocoons while the host larvae are in molting webs at the end of the fourth instar. These cocoons can be seen beneath the surface of the thin molting webs in the fissures of the bark. The adults appear about the middle of May and attack the small host larvae that are emerging rather late from their hibernacula. It was found in the laboratory experiments that unparasitized host larvae remained in hibernation later in the spring than those containing hibernating larvae of *A. solitarius*. The cocoons of this generation of the parasite are formed in 13 to 20 days after egg deposition. From some of them adults issue 7 to 10 days later, but others do not produce adult parasites until the following spring. Those adults that emerge shortly after formation of the cocoons attack the small larvae that are hatching in the field during the second week in July. The life history from this time on is similar to that for the group produced by adults from overwintering cocoons.

In laboratory experiments it was observed that a small number of cocoons of the first generation did not produce adults until the following spring.

From a study of the seasonal history it is evident that *A. solitarius* is well suited to its host. There is little time when there are no adults present, although they do not attack the large larvae so readily as they do the small larvae. The lengthened period during which the host larvae leave hibernation and develop is a distinct aid to the parasite.

EFFECTIVENESS

Hibernating satin moth larvae that have been collected since *Apanteles solitarius* was liberated have been dissected both to ascertain if the species was established in the locality where the collection was made and to determine its effectiveness in reducing the numbers of hibernating hosts. The fact that 1,942 larvae collected in differ-

ent localities prior to the liberation of *solitarius* produced only 3 cases of parasitization by *Apanteles* seemed to justify the determination of any *Apanteles* larvae that were found after the liberations as those of *solitarius*.

The percentage of parasitization has varied considerably in different localities during the same year, and from year to year in the same locality. In large collections it has ranged from just a trace to 30 percent, and in many small collections of less than 100 larvae the percentages have run higher. In 1932 the infestations at most of these collection points were very low in intensity, which made observation and collection very difficult. These observations showed clearly that the parasite was able to persist and do rather effective work. In 15 collections of from 3 to 62 larvae each the percentage of parasitization ranged from zero in 1 collection to 100 in 3 other collections.

Late in October 1933 several satin moth infestations were examined in 11 locations in New Hampshire, 3 in Maine, and 1 in Massachusetts, to determine the effectiveness of *A. solitarius* in reducing the numbers of hibernating *salicis* larvae. The hibernacula were examined and classified, the living larvae collected for dissection, and also the *solitarius* cocoons formed from hibernating *salicis* larvae. By spending a uniform period, 1½ hours, at each location, it was believed that a rough indication of the degree of infestation would be obtained.

The information obtained is presented in table 2.

TABLE 2.—*Results of examination of satin moth hibernacula in 15 towns in New Hampshire, Maine, and Massachusetts in 1933*

Location of infestation	Hibernacula examined	Unparasitized larvae	Larvae parasitized by *Apanteles solitarius*	Larvae parasitized by other species	Larvae dead from unknown cause
New Hampshire:	*Number*	*Percent*	*Percent*	*Percent*	*Percent*
Henniker	112	21.4	65.2	4.5	8.9
Concord	190	41.6	24.2	2.1	32.1
North Chichester	242	19.0	61.6	2.9	16.5
Pittsfield	214	29.0	51.4	4.7	14.9
Alton	129	26.4	46.5	7.8	19.3
Wolfeboro	146	10.3	50.0	2.0	37.7
West Alton	193	20.7	56.5	0.0	22.8
Ossipee	306	20.6	66.7	2.6	10.1
Union	234	56.8	31.6	3.0	8.5
Rochester	212	21.2	58.0	2.4	18.4
Rye	184	33.2	42.9	2.2	21.7
Maine:					
Portland	246	17.1	63.0	2.0	17.9
Ogunquit	191	34.5	44.0	1.6	19.9
Kennebunk	219	26.4	48.4	1.0	24.2
Massachusetts:					
South Yarmouth	193	40.4	14.5	7.3	37.8

It was impossible to determine what percentage of the original population reached the hibernating stage. There is, no doubt, some mortality during the first instar and during the portion of the second instar spent in active feeding before the hibernaculum is formed. Therefore the data presented show the degree of parasitization of that portion of the original population which entered hibernation.

The figures in the table demonstrate that *A. solitarius* has reduced the numbers of *salicis* larvae in hibernation 14.5 to 66.7 percent in

different localities and that in 12 of the 15 towns it effected a parasitization greater than 40 percent. If the intensity of an infestation is judged by the number of hibernacula examined in 1½ hours, it is evident that *solitarius* was very effective in both the lightest and the heaviest infestations.

There will be a further reduction of the host larvae in the spring when they leave their hibernacula and begin feeding, because they are available for attack by *Apanteles* adults appearing at that time.

The writer considers that *Apanteles solitarius* is an effective agent in the reduction of a satin moth infestation, because it is capable (1) of producing a rather high percentage of parasitization, (2) of maintaining itself when the infestation is low in intensity, and (3) of rapid spread. The fact that hibernation occurs in two different forms and that there are several generations a year also increases the effectiveness of the species.

LIMITING FACTORS

Larvae of the genus *Apanteles* in cocoons are subject to considerable attack by other parasites. This subject has been well discussed by Muesebeck and Dohanian (*4*) in the case of *A. melanoscelus* Ratz. According to Proper (*6*), *A. solitarius* is attacked by many of the species that attack *melanoscelus*, as its cocoons are present when these parasites are active. The fact that the species overwinters not only as a prepupa in its cocoon but also as an immature larva is a distinct advantage, for its survival does not depend entirely upon the successful overwintering of cocoons.

The larvae of *Eupteromalus nidulans* (Thomson), a parasite of the hibernating satin moth larvae, doubtless kill some first-instar *Apanteles solitarius* larvae in the hibernating hosts. According to Proper (*5, pp. 44–45*), the adults of *Eupteromalus* kill some satin moth larvae by feeding on the body fluids, and this would result in the destruction of the parasite larvae within such host larvae.

In a few infestations a mite, *Pediculoides* sp., possibly *ventricosus* Newport, was encountered feeding on the *Stilpnotia salicis* larvae and thus killing any *Apanteles solitarius* larvae that they might have contained. This mite is sometimes an effective agent in controlling the host, one infestation having shown 56 percent of the host larvae killed by it at the time of the examination, and there was time for considerable more activity before winter. Brown (*1, pp. 15, 16*) records one instance of the work of *Pediculoides ventricosus* Newport in an infestation of the satin moth in Budapest, Hungary, when it was impossible to find any living larvae of the satin moth in the spring following the first observation of the mite in the infestation. In such event, of course, all *solitarius* larvae present would be destroyed.

From the distribution of *Apanteles solitarius* in Europe there do not appear to be any climatic factors that would limit the distribution or effectiveness of *solitarius* where the host itself could survive.

SUMMARY

Apanteles solitarius (Ratzeburg) is a solitary, internal parasite of the satin moth, a pest of poplar and willow trees. The parasite was

introduced into the United States in 1927 and has been released in 5 towns in Massachusetts, 1 in New Hampshire, and in Kent, Wash. Recently the species has been introduced into Canada from material obtained in New England.

Apanteles solitarius has been reared in the laboratory on several lepidopterous hosts other than the satin moth, but there have been no field recoveries from these hosts. The species lends itself readily to propagation in the laboratory, and methods of doing this are presented. To induce mating was rather difficult, but this was accomplished satisfactorily by starving the females for 8 to 10 hours before introducing them into cages containing food and males. The females oviposit readily and are capable of depositing from 311 to 516 eggs, with an average of 402. The largest number laid by 1 female in 1 day was 53. Unmated females deposit eggs that produce male adults.

The newly deposited egg of *Apanteles solitarius* is nearly transparent, rounded at the cephalic end, enlarged medially, and narrowed posteriorly to a small petiole. The egg measures 0.28 to 0.33 mm, but increases greatly in size before hatching. Only three larval instars have been distinguished. Descriptions of the three instars are presented.

Crossbreeding experiments between *Apanteles solitarius* and *A. melanoscelus* indicate that if these two species crossbreed in nature the tendency will be for each species to retain its identity.

The species overwinters in two forms, as a prepupal larva within a cocoon and as a first-instar larva within the hibernating host. The adults from the overwintering cocoons emerge before those larvae that overwintered in the first instar form cocoons. These adults attack the host larvae coming from their hibernacula and produce cocoons late in May and early in June. The adults from these cocoons attack small larvae of the host, and from this attack some parasite larvae overwinter in the first instar, some cocoons are formed, and a small number of adults may issue. The adults from the overwintering larvae appear about the middle of May. They attack the feeding larvae of the host and produce a generation which in time attacks the very small larvae. The history from this point on corresponds with that for the group produced by adults from overwintering cocoons.

Collections from several towns indicate rapid spread of the parasite and that it is now apparently distributed over the territory in New England infested with the satin moth. From a study of the hibernating form of the host, it is shown that *Apanteles solitarius* effected a parasitization of 14.5 to 66.7 percent, and in 12 of the 15 towns in which observations were made the percentage of parasitization was greater than 40 percent.

The factors that are operating to reduce the effectiveness of *Apanteles solitarius* are the other parasites which attack the host and those parasites which normally attack cocoons of the genus *Apanteles*. There do not appear to be any climatic factors that would limit the effectiveness of this parasite where the host itself could survive.

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UNITED STATES DEPARTMENT OF AGRICULTURE
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FOREST IMPROVEMENT MEASURES FOR THE SOUTHERN APPALACHIANS

By the staff of the Appalachian Forest Experiment Station, Forest Service [1]

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INTRODUCTION

This bulletin deals with the first steps toward the management of the forests of the southern Appalachian region. This region presents a striking example of multiplicity of forest conditions, brought about by many factors operating over long periods on forests in which a great number of tree species are variously associated. It is not practical to recommend improvement measures for the forests of the region, therefore, except as alternative measures among which the man on the ground will make a selection for each individual stand. In order to choose the proper treatment for improving a given stand the forester must be able to recognize, among other things, the stand's component species, its condition, and the productive capacity of the site. Dealing briefly with a great complexity of conditions, the publication indicates what kind of silvicultural work should be done, how it should be done, and where it should

[1] The staff of the Appalachian Forest Experiment Station responsible for this manuscript includes C. A. Abell, Margaret Abell, L. I. Barrett, J. H. Buell, E. H. Frothingham, C. R. Hursh, Ralph M. Nelson, and I. H. Sims.

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be done. Many of the descriptions and recommendations included apply more or less generally to forest conditions elsewhere in the Eastern States.

The southern Appalachian region (fig. 1) consists of two long, rugged mountain systems: On the west, the Alleghenies and the Cumberlands; and on the east, the Blue Ridge and Smoky Ranges and cross ranges. The mountain slopes are mostly forest land.

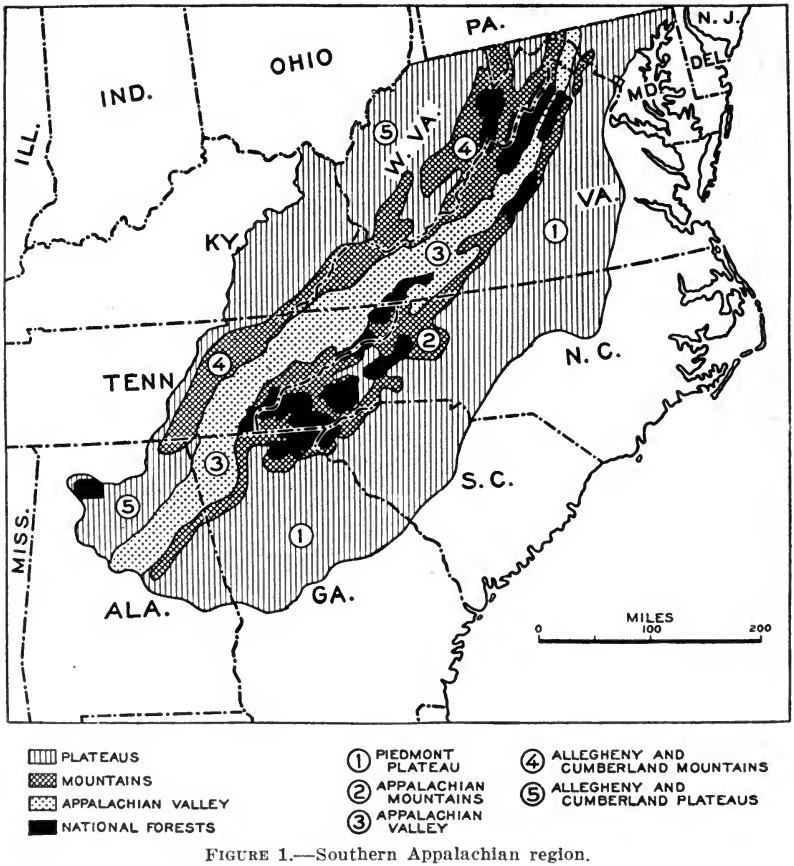

FIGURE 1.—Southern Appalachian region.

STAND IMPROVEMENT

The chief purposes of stand-improvement work are (1) to bring run-down or inadequately productive forest stands into better condition to produce timber, and (2) to protect watershed and soil values. A third purpose, in the Appalachian region, is to create or maintain conditions favorable to game.

From the timber-production point of view, the conditions to be dealt with fall generally into four classes: (1) The presence of defective, unmerchantable old-growth trees that impede or prevent the development of a young and vigorous stand; (2) overdensity of second-growth stands, and the presence in such stands of defective trees and poor species that reduce both the quality and the

potential growth rate of the stands; (3) the presence, in young reproduction that has followed cutting or fire, of large numbers of worthless shrubs, vines, and tree sprouts and large numbers of seedlings that are defective or of poor species; and (4) the absence of desirable reproduction, usually a result of repeated burning. Correcting these conditions involves: (1) Making improvement and liberation cuttings in the old growth; (2) making improvement cuttings and thinnings in the second growth; (3) cleaning the reproduction; (4) providing for new reproduction by insuring a natural seed supply and good seed-bed conditions; and (5) underplanting.

For erosion control and watershed protection, forest stands should be maintained on critical areas, lands abandoned for agriculture should be planted with forest trees, and the water-absorptive capacity of forest soils should be increased through supplemental measures.

Maintenance of game animals and birds requires provision of cover and food. Some trees bearing fruits and nuts valuable as game food are relatively poor for timber production. Therefore, stand-improvement operations designed both to promote timber production and to preserve conditions favorable to game generally involve compromise.

The specific stand-improvement treatment needed on a given area depends upon stand composition, site, and other factors including the density and quality of overstory and understory, respectively. Before improvement measures are described, these factors will be briefly discussed.

MAJOR FOREST TYPES

Forest tree species native to the Appalachian region number about 120. About 55 of these, including about 45 species of hardwoods, are important commercially.[2] These species occur in many different combinations (forest types), which for convenience will be grouped in this publication in six major forest types: Spruce, northern hardwood, oak-chestnut, cove hardwood, yellow pine-hardwood, and white pine-hardwood.[3] In the descriptions that follow (except in that of the spruce type), the characteristic species of each of these six forest types are grouped approximately according to their relative importance for timber production. (Within groups, the order in which the species are listed does not signify relative desirability.)

SPRUCE

The spruce type of the southern Appalachians occurs at elevations of 3,200 feet or more in West Virginia and of 4,500 feet or more in Virginia, Tennessee, and North Carolina. It occupies only a small total area. The largest areas forested with this type center on the Black Range and on the Great Smoky and Balsam Mountain Ranges. The most extensive remaining virgin stands of spruce occur in the Great Smoky Mountains National Park. Clear cutting has been practiced in harvesting forests of this type, and almost without exception the logged areas have been burned over.

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[2] A list of the principal forest tree species of the region, including scientific as well as common names, appears in the appendix.

[3] The relationship of these six major types to the forest types recognized by a committee of the Society of American Foresters is shown in the appendix.

The burned areas need to be planted, but except on fresh burns the presence of dense thickets of pin cherry, shrubs, briars, and weeds, or of the reproduction of yellow birch and other hardwood trees, makes this an expensive procedure. Native spruce and balsam are the best species to plant on these areas. It is recommended that 2-1 planting stock be used, spaced 8 by 8 feet. For the poorer sites 2-2 stock is recommended.

Where uncut stands of spruce and balsam border burned and cut areas, these species may seed in naturally. Any unmerchantable old hardwoods or unpromising young hardwoods overtopping reproduction of such origin should be removed. The areas on which this treatment is needed are probably very small.

NORTHERN HARDWOOD

Northern hardwoods in the Appalachian region occupy the higher coves, and slopes and ridges at elevations of more than 2,000 feet in the northern and 3,000 feet in the southern part of the region. On the better sites the northern hardwood forest produces excellent timber; but on the higher ridges, where the soil is thin and climatic factors adverse, it produces only short-boled trees. Much of the area occupied by the northern hardwoods is relatively inaccessible, and in consequence the heaviest cutting and culling in forests of this type have usually taken place at the lower altitudes and on the better sites. In the culled stands the present dominant old-growth canopy is made up of the most defective of the timber trees that were present in the original stand together with such species as were not sought at the time of cutting. Often an understory of reproduction of such shade-tolerant species as hemlock and sugar maple was already present when the logging was done. Dense growths of less desirable species such as beech, mountain maple, and hophornbeam also occur.

The forest species included in the type are named in the accompanying list.

SPECIES INCLUDED IN THE NORTHERN HARDWOOD TYPE,[4] CLASSIFIED ACCORDING TO DESIRABILITY FOR TIMBER PRODUCTION

Better sites	*Poorer sites*
Desirable:	Desirable:
Red oak	Red oak
Basswood	Northern white pine
Sugar maple	Yellow birch
Black cherry	Black locust
White ash	
Yellow poplar	
Cucumber magnolia	
Yellow birch	
Less desirable:	Less desirable:
Northern white pine	Chestnut oak
Sweet birch	Red maple
White oak	Eastern hemlock
Black locust	
Hickory	
Red maple	
Elm	
Eastern hemlock	
Butternut	

[4] Key species: Sugar maple, yellow birch, beech.

Better sites	*Poorer sites*
Least desirable:	Least desirable:
Buckeye	Buckeye
Beech	Beech
Chestnut	Chestnut
Mountain magnolia	Mountain maple
Mountain maple	Striped maple
Striped maple	Pin cherry
Pin cherry	Mountain-laurel
Rhododendron	Rhododendron

OAK-CHESTNUT

The oak-chestnut type has an extremely wide altitudinal range in the southern Appalachian region, from 1,000 to 4,000 feet. It occurs on all sites within this range but particularly on the drier sites, which it shares with the yellow pine[5]-hardwood type. If yellow pine seed trees are present in or near a stand of oak-chestnut, pine reproduction may become established through silvicultural measures, or may enter the stand naturally after fire, wind throw, or blight killing of chestnut. The better sites on which the oak-chestnut type occurs are shared with various cove hardwoods; on the best sites it is not uncommon to find cove hardwoods entering the stand following ravages of chestnut blight. The oak-chestnut type shares some better sites with the white pine-hardwood type, also, and its composition may be materially influenced by the latter type.

Below 2,000 feet, particularly on the Cumberland Plateau, the proportion of chestnut in the stands is considerably less.

Stands rendered unproductive by repeated culling are common within the oak-chestnut forest. Frequently the old-growth overstory is made up almost entirely of defective trees, and the associated understory is sometimes composed of weed species. This condition represents one of the most difficult of silvicultural problems. For the most part, growing-stock conditions are now better in stands that were heavily cut than in stands that were repeatedly culled.

Forest species included in the oak-chestnut type are named in the accompanying list.

SPECIES INCLUDED IN THE OAK-CHESTNUT TYPE,[6] CLASSIFIED ACCORDING TO DESIRABILITY FOR TIMBER PRODUCTION

Better sites	*Poorer sites*
Desirable:	Desirable:
Red oak	Black oak
White oak	Chestnut oak
Yellow poplar	Southern red oak
Black locust	
Black oak	
Southern red oak	
Less desirable:	Less desirable:
Scarlet oak	Black locust
Red maple	Dogwood
Hickory	Scarlet oak
Dogwood	Post oak
Persimmon	Hickory

[5] "Yellow pine" is used in this bulletin to indicate shortleaf, Virginia, pitch, and mountain pines.

[6] Key species: Scarlet oak, chestnut oak, black oak, chestnut.

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Better sites	*Poorer sites*
Least desirable:	Least desirable:
Black gum	Black gum
Beech	Red maple
Chestnut	Chestnut
Silverbell	Blackjack oak
Sassafras	Sourwood
Witch-hazel	Sassafras
Chinquapin	Persimmon
Rhododendron	Witch-hazel
Mountain-laurel	Chinquapin
	Mountain-laurel

COVE HARDWOOD

The cove hardwood forest is found mostly in narrow coves and on moist slopes at elevations of from 500 to 5,000 feet, but at its best between 2,000 and 4,000 feet. This forest represents the best opportunity for profitable forest management in the mountains, since it contains a large number of valuable, rapidly growing species and since the stands recover rapidly from cutting and fire.

The cove-hardwood forests have generally been heavily logged, and the remaining old-growth timber is mostly difficult of access. Some of the less accessible stands have become overmature and are actually retrograding on productive sites, preventing the land from becoming available for a vigorous growing stock. Moisture and soil conditions are usually favorable, but owing to the dense shade no reproduction except of the most shade-tolerant species is present. A dense growth of mountain-laurel and rhododendron sometimes makes up the understory for the cove-hardwood forest; but this is not usually the case on the best sites in the mountains, where the soil is generally less acid than on surrounding areas.

Forest species included in the cove-hardwood type are named in the accompanying list.

SPECIES INCLUDED IN THE COVE-HARDWOOD TYPE,[7] CLASSIFIED ACCORDING TO DESIRABILITY FOR TIMBER PRODUCTION

Better sites	*Poorer sites*
Desirable:	Desirable:
Yellow poplar	Yellow poplar
Red oak	White oak
Black cherry	Red oak
Black walnut	Northern white pine
White ash	Black oak
Cucumber magnolia	Black cherry
Basswood	Black locust
White oak	
Less desirable:	Less desirable:
Black oak	Black walnut
Black locust	Eastern hemlock
Hickory	Scarlet oak
Eastern hemlock	Hickory
Sweet birch	Sweet birch
Dogwood	Dogwood
Red maple	Red maple

[7] Key species: Yellow poplar, eastern hemlock, cucumber magnolia, basswood.

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Better sites	*Poorer sites*
Least desirable:	Least desirable:
Buckeye	Black gum
Black gum	Buckeye
Beech	Chestnut
Chestnut	Sourwood
Scarlet oak	Sassafras
Silverbell	Rhododendron
Sassafras	Mountain-laurel
Rhododendron	
Mountain-laurel	

YELLOW PINE-HARDWOOD

The name "yellow pine-hardwood type" is applied to stands characterized by yellow pines mixed with upland hardwoods, largely oaks. The yellow pine-hardwood forest is found on moderately dry to very dry soils, extending from the piedmont and other plateaus, at altitudes of 500 feet or less, to elevations of 3,500 feet in the mountains. It reaches its best development on well-drained slopes and plateaus usually below the elevation of 2,500 feet. In the mountains it usually occupies the drier south or west exposures. At the lower elevations it commonly occupies better sites, and shortleaf pine is the most abundant and desirable of the yellow pines. Virginia pine is frequent at the lower altitudes. At the southern extremity of the Appalachian region, loblolly pine occasionally enters the type. Virginia pine and shortleaf pine are replaced by pitch and mountain pine at the higher elevations in the mountains. The pines and the many hardwood species associated with them in this type are named in the accompanying list.

SPECIES INCLUDED IN THE YELLOW PINE-HARDWOOD TYPE,[8] CLASSIFIED ACCORDING TO DESIRABILITY FOR TIMBER PRODUCTION

Better sites	*Poorer sites*
Desirable:	Desirable:
Shortleaf pine	Shortleaf pine
Northern white pine[9]	Pitch pine[9]
Black oak	Mountain pine[9]
White oak	Chestnut oak[9]
Chestnut oak[9]	Virginia pine
Southern red oak	Black oak
Pitch pine[9]	Southern red oak
Virginia pine	
Less desirable:	Less desirable:
Black locust	Scarlet oak
Hickory	Post oak
Scarlet oak	Hickory
Mountain pine[9]	Dogwood
Red gum	
Dogwood	
Persimmon	
Least desirable:	Least desirable:
Black gum	Black gum
Red maple	Red maple
Post oak	Blackjack oak
Chestnut	Chestnut
Sourwood	Sourwood
Blackjack oak	Sassafras
Sassafras	Silverbell[9]
Silverbell[9]	Chinquapin
Mountain-laurel[9]	Turkey oak
	Mountain-laurel[9]

[8] Key species: Shortleaf, pitch, Virginia, and mountain pines.
[9] Species particularly abundant in the yellow pine-hardwood forest at higher altitudes.

The yellow pine-hardwood type is rarely found on sites I and II except in old fields.

This type may be said to share the drier sites with the oak-chestnut type. It may be considered simply as a dry-site form of the oak-chestnut type with the addition of yellow pine. Huckleberry and grasses often form a ground cover that interferes with the establishment of desirable tree reproduction.

On most of the areas on which the yellow pine-hardwood forest is commonly found, light to moderate cuttings have usually removed the pine, owing to the fact that the species has made much better growth and produced more desirable timber than have the hardwoods. The effect of these cuttings combined with the presence of undesirable advance growth has brought about an outstanding need of silvicultural improvement. In some cases advance growth of pine and desirable hardwoods is seriously overtopped by old-growth hardwoods of inferior quality. Also, on many areas, the future development of this young pine reproduction is jeopardized by competing growth of undesirable hardwoods and shrubs. Situations are common in which satisfactory yellow pine seed trees are available. In such situations the logical procedure, in the absence of desirable hardwoods, is to make every effort to increase the proportion of pine. The major difficulties in the way are most frequently dense herbaceous cover and unfavorable light conditions.

WHITE PINE-HARDWOOD

The white pine-hardwood type in the southern Appalachian region is found between altitudinal limits of 1,500 and 5,000 feet. Within the altitudinal ranges of the oak-chestnut and the yellow pine-hardwood types this type is often associated with the former on good sites and with the latter on the drier sites. Northern white pine rarely occupies an important place in the old-growth overstory. With better fire protection during the past decade it has, however, become important in the understory over a considerable area. The shade tolerance of white pine is such that the species is able to survive and make good growth in its younger stages while still overtopped. However, mechanical interference of the hardwood branches invariably injures the pine leaders, resulting in poor form. The growth rate and general desirability of the species justify giving every opportunity to white pine in the understory on good sites. It appears to be good silviculture to treat stands containing white pine with the idea of increasing the proportion of the species wherever possible.

Forest species included in the white pine-hardwood type are named in the accompanying list.

SPECIES INCLUDED IN THE WHITE PINE-HARDWOOD TYPE,[10] CLASSIFIED ACCORDING TO DESIRABILITY FOR TIMBER PRODUCTION

Better sites	*Poorer sites*
Desirable:	Desirable:
Northern white pine	Northern white pine
Yellow poplar	Black oak
Red oak	White oak
Black oak	Red oak
White oak	Chestnut oak
	Southern red oak
Less desirable:	Less desirable:
Eastern hemlock	Scarlet oak
Hickory	Hickory
Red maple	Dogwood
Dogwood	
Birches	
Least desirable:	Least desirable:
Black gum	Black gum
Chestnut	Red maple
Beech	Chestnut
Scarlet oak	Sourwood
Sourwood	Mountain-laurel
Silverbell	Rhododendron
Rhododendron	
Mountain-laurel	

FOREST SITES

"Forest site" sums up the environmental factors that affect the composition of the forest and its rate of growth. These are chiefly climatic and soil factors. Atmospheric and soil moisture are probably the most important. Most trees grow better, other conditions being equal, on deep moist soils and in cool moist air than on shallow soils in dry sunny situations exposed to drying winds.

The most productive sites in the Appalachian region are found in the coves and stream bottoms, and on moist benches and northerly slopes. There the soil is usually a deep, friable, dark-brown loam. In contrast with the coves, which represent the best of the productive sites, the upper slopes and ridges usually represent the poorest sites. There the soil is shallow and lacks fertility. Occasional rock outcrops and cliffs occur, and the soil frequently contains a considerable quantity of rock fragments. North and east slopes are usually moist and contain a greater proportion of highly productive area than south or west slopes.

Moist sites are favorable to many desirable species and produce dense, rapidly growing stands; on such sites mature trees contain 3 to 5 or more logs each. On dry sites the timber, particularly that of hardwood species, is short-bodied, mature trees containing from one-half to one and one-half logs each, stands are open, and the number of species present in the dominant canopy is frequently limited to 4 or 5. Damage due to past fires is likely to be greater on the dry south and west slopes than on slopes with a north or east exposure.

Since forest tree species differ in their ability to withstand poor site conditions, the distribution of forest types depends largely upon

[10] Key species: Northern white pine.

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site. Certain species including yellow poplar, eastern hemlock, and basswood grow only on relatively moist soils and hence are characteristic of the cove hardwood type. Chestnut oak, scarlet oak, black oak, and the yellow pines are examples of species able to endure much drier conditions.

Apparent exceptions to the moist- and dry-site relations just described are frequently met, as when forest unquestionably of the cove-hardwood type is found on or near the tops of ridges, particularly in gaps. The explanation of such occurrences lies in the presence of pockets of relatively deep and fertile soil, resulting from the weathering of soft rock strata underlain by harder strata in the complex geologic folding that often prevails. The soil thus formed may have sufficient depth and a sufficiently continuous moisture supply to maintain cove hardwoods permanently. On the other hand its moisture supply, although sufficient to support a luxuriant vegetation during wet cycles of years, may be entirely insufficient to do so during drought years. Where this is the case the older forest vegetation includes only drought-resistant species, such as chestnut oak and pitch pine, although much of the tree reproduction, in moist cycles of years, may be of cove species such as yellow poplar or hemlock. The key to the permanence of moist conditions on ridge tops therefore lies in the composition of the older forest, and the choice of species to be favored in stand-betterment measures should rest upon the character of the old growth, where such growth is present.

Site quality can be materially reduced by erosion, and old fields that were cultivated for a considerable period are likely to have lost much of their fertility for timber production. The first generation of trees grown on such soils cannot be counted upon to grow thriftily. In particular, pine stands on "worn-out" old fields should not be expected to produce more than pulpwood during the first rotation.

As has been indicated in the discussion of forest types, a rough correlation exists between elevation and the associations of species. For instance, the spruce-balsam forest is found only at the highest elevations, the northern hardwoods at somewhat lower altitudes, and other forest types still lower. In the southern Appalachians there is no sharply defined altitudinal banding of types, however.

The northern-hardwood, cove-hardwood, and white pine-hardwood types are characteristic of north rather than south exposures, and the reverse is true of the yellow pine-hardwood type and the dry-site phases of the oak-chestnut type.

Where there is doubt as to which of the major types is present, the following generalized list of species characteristic of dry and of moist sites may be used as a guide in deciding upon the species to be favored for timber production:

DRY-SITE [11] SPECIES

Desirable	*Less desirable*	*Least desirable*
Northern white pine	Hickory	Post oak
Chestnut oak	Black gum	Persimmon
Black locust	Red maple	Blackjack oak
Shortleaf pine	Scarlet oak	Sassafras
Black oak	Mountain pine	Serviceberry
Eastern red cedar	Carolina hemlock	Sourwood
Virginia pine	Dogwood	Chestnut
Southern red oak		Chinquapin
Pitch pine		Silverbell
		Mountain-laurel

MOIST-SITE [12] SPECIES

Desirable	*Less desirable*	*Least desirable*
Yellow poplar	Eastern hemlock	Chestnut
Black walnut	Beech	Blue beech
Northern white pine	Buckeye	Pin cherry
White ash	Hickory	Crab apple
Red oak	Dogwood	Hawthorns
White oak	Red maple	Hophornbeam
Black cherry	Sweet birch	Mountain magnolia
Sugar maple	Butternut	Umbrella magnolia
Basswood	Sycamore	Striped maple
Cucumber magnolia	Black gum	Red mulberry
Black locust	Coffeetree	Mountain-ash
Yellow birch	Elm	Redbud
Red spruce	Honeylocust	Rhododendron
	Red gum	Silverbell
	Holly	Witch-hazel
	River birch	
	Black willow	
	Southern balsam fir	

CLASSIFICATION OF SITE QUALITY

Site quality is ordinarily defined in terms of the height attained by dominant trees at a given age. On this basis the sites represented in the northern hardwood, oak-chestnut, cove-hardwood, white pine-hardwood, and yellow pine-hardwood forests of the southern Appalachian region have been classified by the Appalachian Forest Experiment Station in four groups. For many stand-improvement operations precise identification of site quality is not necessary. Table 1 will be useful chiefly in rough determination of sites, effected by estimating the heights of mature dominant trees and comparing the estimated heights with the heights shown in the table, in which is also indicated the average volume per acre, in board feet, of virgin stands on these sites.[13]

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[11] The yellow pine-hardwood type is characteristic of dry sites. The oak-chestnut type occurs usually on dry sites, although it sometimes occurs on moist sites.

[12] The types characteristic of moist sites are spruce, northern hardwood, cove hardwood, and white pine-hardwood. (The last mentioned is occasionally found on dry sites.)

[13] Yields per acre for 5 sites are shown in table 8 of Timber Growing and Logging Practice in the Southern Appalachian Region, U. S. Dept. Agr. Tech. Bull. 250.

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TABLE 1.—*Classification of forest sites for the southern Appalachian region*

Site	Height of dominants at maturity			Volume of stands per acre [1]		
	Hardwoods	Yellow pine	White pine	Hardwoods	Yellow pine	White pine-hemlock
	Feet	*Feet*	*Feet*	*M bd. ft.*	*M bd. ft.*	*M bd. ft.*
I. Coves	120+	125+	160+	8 and more.	12 and more.	16 and more.
II. Lower slopes	90–120	95–125	135–160	5–7. 5	7. 5–11. 5	10–15. 5
III. Middle and upper slopes	65–90	75–95	105–135	3–4. 5	4. 5–7	6–9. 5
IV. Ridge (largely unmerchantable)	40–65	45–75	75–105	1–2. 5	1. 5–4	2–5. 5

[1] These volumes are for the average virgin stands found in the southern Appalachians.

CLASSIFICATION OF STANDS FOR SILVICULTURAL TREATMENT

RELATIVE DESIRABILITY OF SPECIES

On pages 4–9 the southern Appalachian timber species have been classed according to their desirability for timber production as indicated by present knowledge. The logging history of the region has repeatedly proved that the relative commercial values of the different tree species are not stable. New developments have continually arisen to bring little-used species into economic importance. At present few of the region's forest tree species are without promise of commercial value. Since the extension of utilization is likely to go on indefinitely, the choice of species to be encouraged for future production should be based not so much upon present demand as upon growth rate, mature size, form, soundness, vigor, resistance to fire damage, freedom from insect enemies and from disease, and the technical properties of the wood. Trees having wood qualities adaptable to more than one type of use are in general those most likely to maintain a stable value.

The desirability of certain tree species varies with site conditions. Yellow poplar, for example, should not be favored except on relatively moist soil. Certain other species, such as scarlet oak, make good growth on a wide variety of sites but because of the inferior quality of their products, or for some other reason, should not usually be favored on good sites. Thus on the better sites scarlet oak should be discouraged in favor of such species as yellow poplar, northern white pine, red oak, or even black oak, but on some poorer sites it should perhaps be encouraged. Among individual stands the desirability of a given species varies with composition, density of stocking, and vigor. Each stand must be considered with the idea of best utilizing the potentialities of the area which it occupies. On better sites it is a mistake to permit land to be permanently held except by species that will grow rapidly and yield valuable products. Consequently intensive treatment is justified on the better sites.

Dogwood and persimmon are rated in the foregoing lists as "least desirable" or "less desirable" for timber production chiefly because of small size and, particularly in the case of dogwood, slowness of growth to merchantable size, density of foliage, and abundance of sprouts (which may seriously interfere with seedlings and sprouts

of other species). These species, however, produce special products of relatively high value; dogwood leaves decay quickly and help to maintain good soil conditions; and both dogwood and persimmon contribute food for game. For these reasons, both species are to be rated as generally undesirable only when their abundance or crown spread constitutes a threat to reproduction of desirable timber species.

Other species desirable as providing game food or cover are named in the section Measures Designed to Encourage Game, page 35.

DESIRABILITY OF INDIVIDUAL TREES

Important as it is to provide that future stands shall consist mainly of the best species, it is at least equally important to eliminate poor, stunted, or defective trees, regardless of species, in favor of promising trees of good form and thrift. Sound, vigorous trees should be favored regardless of whether commercial timber production or watershed and soil protection is the chief object of the stand-improvement operation. Whether an individual tree is or is not sound and vigorous depends on its past history and its position in the stand.

SPROUT GROWTH

It is generally believed that seedlings are silviculturally preferable to sprouts. While a sprout usually grows faster in the juvenile stages it does not have the sustained vigor of a seedling and is much more likely to rot at the base. In general, the larger the stumps the less desirable are the sprouts. Sprouts from stumps less than 2 inches in diameter are practically as desirable as seedlings; these may be termed "seedling sprouts." Of all the southern Appalachian species only basswood and chestnut produce successful sprouts from stumps of saw-log diameter. Chestnut, of course, is out of consideration because of the blight. Of the oaks, chestnut oak is the most prolific and persistent sprouter. Sourwood, dogwood, black gum, and sassafras are among the less desirable species that sprout prolifically.

DAMAGE, ABNORMALITY, AND DISEASE

Stand improvement involves the removal of trees affected by any injury that threatens to nullify or seriously reduce their value. Rot, broken branches, and open wounds along the trunk are common types of defect. A prevalent cause of open wounds is fire. This form of injury is always present in stands that have frequently been burned. Fire damage is so common, in fact, that in some stands all the trees are scarred and only the worst damaged ones can be designated for removal in improvement operations.

Any open wound, caused by either fire, logging, or the breaking of limbs by wind or ice, presents a chance for the entrance of decay and insects. Trees with large scars, such as are caused by repeated fires, are particularly undesirable. Even though a wound has healed over, it may first have served as the point of entrance of decay that has subsequently spread up the trunk from the wound. Any appearance of decay, such as rot in an unhealed scar or as fungous fruiting bodies (conks) on the trunk or branches, establishes good reason for removing a tree. Insect-infested trees and trees that bear considerable quantities of mistletoe or witches'-broom should be removed.

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Ice storms have been responsible for much breakage of tree branches and much bending or breakage of the trunks of small trees. Besides opening wounds through which rot may enter, severe ice breakage may ruin the form of a tree for utilization and retard its growth.

Serious abnormalities that affect the value of trees and constitute reason for removal include abnormal swellings, dead tops, abrupt crook or gradual bend (sweep), fork, and excessive limbiness. Trees that have been left standing when those around them were cut frequently exhibit many small new branches (water sprouts) along the trunk. Unless these are exceptionally numerous they do not usually constitute in themselves a reason for removing the tree. Most of them will be killed by shade.

The southern pine beetle periodically becomes epidemic in the region and causes considerable damage. The death of scattered groups of pines can usually be attributed to attacks by this insect. Fading of the foliage and the presence of pitch tubes, but more especially the presence of winding S-shaped tunnels in the inner bark, are reliable indicators of infestation. Where insect infestation is involved, efforts directed toward the reduction of insect broods are the most important feature of cultural operations. Such reduction can be effected by felling and peeling infested trees and burning the bark and tops. This treatment should precede emergence of the adult insects. Under favorable conditions the southern pine beetle develops from egg to adult in 30 to 40 days. (Other important forest insects of the southern Appalachians are listed in the appendix.)

Dead trees need not ordinarily be removed from the stand except where it is important to preserve scenic values, as along roads, or where an extreme fire hazard exists. The southern Appalachian forests now contain an unusual number of dead and dying trees—largely chestnut trees, victims of the chestnut blight (*Endothia parasitica*). The death of these trees opens up the crown cover just as if it had resulted from girdling. Liberation cuttings in stands containing many dead or dying trees may therefore be concentrated on the removal of the living defective trees of species other than chestnut. In places it may be necessary to make cleanings in dense clumps of chestnut sprouts that are threatening other small growth of desirable species.

VIGOR, GROWTH RATE, AND SUPPRESSION HISTORY

An estimate of vigor can be made by observing the general size, form, and luxuriance of the crown, the rate of growth, and (particularly in pines, hemlock, and other conifers) the length of the leaders. Many trees suppressed for a long time are unable to respond to release. These cases are usually apparent from the crookedness of the tree, the unhealthiness or thinness of the foliage, and the flattening of the crown on top.

Since one of the major purposes of stand-improvement work is to accelerate the rate of growth, only those trees should be left that have made or are capable of making good growth on the site. Differences in diameter growth rate are largely due to differences in the degree of competition to which the individual trees are subjected. The rate of diameter growth can be ascertained by the use of the increment borer, a tool specifically designed to remove radially a small cylinder

of wood. For most species the number and width of annual rings can easily be determined from such a cylinder.

On the better sites, trees of the faster growing species, such as yellow poplar and the pines, unless they are being severely crowded, usually have growth rings wider than one-tenth inch. On the poorer sites uncrowded trees may show annual rings as narrow as one-fifteenth inch.

As the stands grow older and the trees increase in size, competition between individuals becomes more severe and, unless reduced by thinnings, leads to reduction in rate of diameter growth. In second-growth stands, need of thinnings is generally indicated if the growth of the dominant trees during the last 10 years is less than that shown for the preceding decade. In making thinnings, the selection of trees to be left should be based largely upon the condition of the tree crown and its position in the crown canopy.

Large spreading trees with branches extending well down along the bole, even though vigorous, are undesirable both because of the low grade of their lumber and because of the excessive space they occupy.

SHRUBS, VINES, AND WEED TREES

Over extremely large areas that have been logged the establishment of a satisfactory stand of timber is a problem not because desirable tree reproduction is absent but because of the presence of dense shrub thickets, of spreading vines, or of commercially worthless tree species. Common shrubs and vines of the southern Appalachian region are listed in the appendix. Some of these neither grow large enough nor occur in sufficient quantities to do much damage to the tree stands; others are very injurious, but are not very widely distributed; still others constitute a most difficult reforestation problem over extensive areas.

In the last-mentioned class the worst are mountain-laurel and two large species of rhododendron: *Rhododendron maximum*, occurring at altitudes below those of the spruce type, and *R. catawbiense*, occurring within the range of spruce and sometimes at lower altitudes. Mountain-laurel and rhododendron, frequently growing together in dense thickets, constitute an evergreen barrier to reproduction even of shade-tolerant tree species. Tree seedlings penetrate such thickets only in scattered openings. Possibility of satisfactory tree reproduction is still more remote if unmerchantable trees have been left standing after logging. A further hindrance to seedling establishment is the acid soil condition characteristic particularly of rhododendron thickets. Numerous other common shrubs (indicated by boldface type in the appendix) sometimes interfere with the reproduction of desirable trees, particularly on cut-over areas that have been burned. Shrubs that frequently obstruct the establishment of desirable timber stands are blackberry, huckleberry, sumac, and sweetfern on the drier sites, and the same with alder, hydrangea, and many others on moist soils. Tree seedlings ultimately spring up here and there in spite of the competition, but commonly so far apart that they develop into wide-spreading, limby trees such as do not produce commercial material.

Of the vines, grape is by far the most injurious. Dutchman's pipe does a good deal of damage locally, but is not so common or so

destructive as grape. Grapevines frequently spread out over the tops of young second growth in patches of as much as one-fourth acre, bending the young trees over and ruining the stand.

Many small tree species, practically worthless commercially, frequently occur in sufficiently dense thickets to prevent the development of desirable trees that are present on the area. Such species, sometimes termed "weed trees", are indicated by asterisks in the tree list in the appendix. The most wide-spread and troublesome of these are sassafras, sourwood, silverbell, dogwood, and pin cherry.

STAND CONDITIONS

The classification of stand conditions adopted here, based on the condition of overstory and understory, stocking, soundness, and desirability of species, is shown in tables 3, 4, and 5 (pp. 25, 28, and 34), together with the improvement measures recommended for each condition class.

The following definitions are given to facilitate the use of tables 3, 4, and 5:

"Overstory" (dominant canopy) is the term applied to the dominant and codominant trees collectively. "Understory" refers to the intermediate and overtopped trees collectively.

"Dominant canopy good" refers to the percentage of dominants and codominants in the stand that are, or will develop into, sound trees of merchantable quality. In the case of old growth, a good dominant canopy has been defined as one that contains 75 to 100 percent of such desirable trees. In the case of a young stand, a good dominant canopy is one containing 60 to 100 percent of desirable trees.

"Dominant canopy poor" indicates a lower percentage of desirable trees in the dominant canopy than that implied by "dominant canopy good."

"Good stocking of desirables in understory" implies the presence of reproduction of desirable species distributed at the rate of at least 1 stem to every 15-foot square (or about 200 trees per acre) when the trees are less than 15 feet high, and at the rate of at least 1 stem to every 21-foot square (or 100 trees per acre) when the trees are 15 feet high or higher. A satisfactory compromise procedure for extensive areas supporting stands differing in height is to leave desirable trees at the rate of 1 stem to every square rod, or 160 trees per acre.

"Competition of undesirables severe" implies that competition threatens to reduce the stocking of desirable species below that defined as *good*.

"Competition of undesirables not severe" implies that competition does not threaten to reduce stocking of desirable species below that defined as *good*.

"Poor stocking of desirables in understory" implies a stocking of less than 200 well-distributed desirables per acre for trees less than 15 feet high, or of less than 100 well-distributed trees per acre for trees more than 15 feet high.

"Competition of undesirables severe" implies that competition precludes good stocking.

"Competition of undesirables not severe" implies that competition does not preclude good stocking.

In tables 3, 4, and 5 the term "old growth" applies to all stands containing an overstory of trees 15 inches or larger in diameter at breast height; "second growth" refers to stands in which the diameters of the dominant trees are prevailingly as large as 4.5 inches and less than 14 inches; and "new growth" refers to reproduction less than 4.5 inches in diameter.

The terms "overstory" (dominant canopy) and "understory" are used in the tables for each of the three primary classifications, old growth, second growth, and new growth, although the terms refer to widely different size groups of trees. To avoid confusion this concept must be kept clearly in mind. In old-growth stands the dominant canopy (i. e., dominants and codominants) may consist of trees from 15 to 30 or more inches in diameter at breast height, and the understory may contain trees up to 14 inches or even larger in diameter. On the other hand new growth occupying openings on a heavily cut-over area may have a dominant canopy consisting of hardwood sprouts 6 or 8 feet tall, and a suppressed understory of white pine seedlings only 1 or 2 feet tall. The meanings of the terms "overstory" and "understory", as used in tables 3, 4, and 5, respectively, are illustrated in figure 2.

The first step in applying tables 3, 4, and 5 in the field is to determine whether the stand falls into the classification old growth (table 3), second growth (table 4), or new growth (table 5). The next step is to determine the quality of the trees in the dominant canopy. If this is found to be good the next step, in the case of a stand of second growth, is to determine the grade of competition existing in the stand. Observations as to the general thrift of the stand should be supplemented with increment borings in dominant trees, which will show whether crowding is reducing the growth rate appreciably. In general, dominant second-growth trees should have made as great an increase in diameter in the last 10 years as in the previous decade. If competition due to heavy stocking is found to be reducing the growth rate, the stand is classified as condition class 6, table 4. The treatment recommended involves thinning to release a certain number of the best dominant trees in the stand. If the observations and increment borings indicate that competition is retarding the growth rate but little, if at all, the stand is classified as condition class 7, for which no treatment is needed.

The forest presents so many differences within small areal units that frequent variation in improvement practice is necessary.

Certain condition classes, without doubt, occur more commonly than others. Forest exploitation in the southern Appalachians has involved heavy logging of the best stands, so that now large areas of highly productive land are occupied by new growth. On such areas condition classes 14 and 16 are most common. Over large areas that are relatively inaccessible, and in extensive stands of mediocre timber, only the best trees have been removed. In such forests condition classes 2 to 5, inclusive, occur most commonly.

The measures recommended in tables 3, 4, and 5 are general measures that must be modified to meet the requirements of each stand under consideration.

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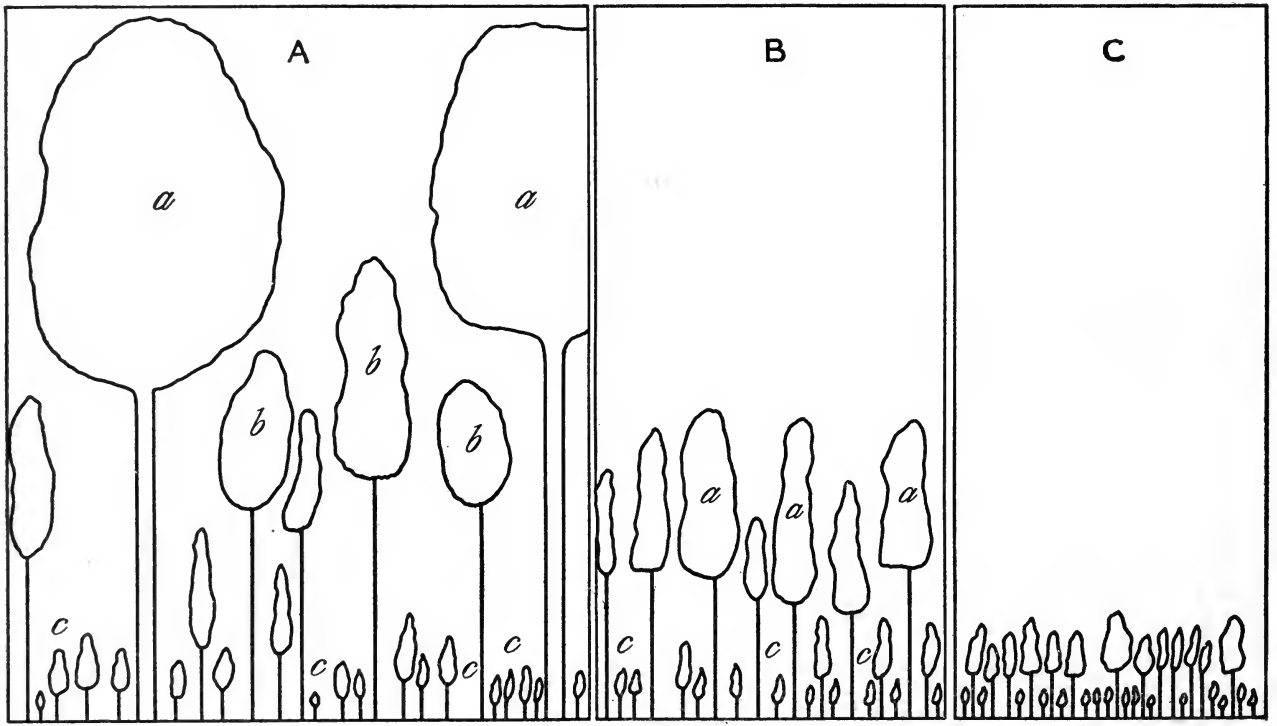


FIGURE 2.—Diagram illustrating various overstory-understory relationships: *A*, Overstory of old growth (*a*), with subordinate second growth (*b*), and new growth (*c*). Treatments outlined in table 3. *B*, Overstory of second growth (*a*). Treatments outlined in table 4. *C*, New growth overtopping smaller new growth. Treatments outlined in table 5.

GENERAL IMPROVEMENT MEASURES

DEFINITIONS

The classification of forest-improvement measures used in this text follows closely definitions formulated in 1917 by a committee of the Society of American Foresters.[14] The definitions used here are as follows:

Cleaning.—Cutting made in a stand not yet past the sapling stage (that is, in new growth) for the purpose of removing shrubs (and herbaceous growth), vines, and trees of undesirable form or species that are injuring or are likely to injure promising trees. Synonym: Weeding.

Thinning.—Cutting made in a dense immature (second-growth) stand for the purpose of increasing the growth rate of the trees that are left and of improving the composition and quality of the stand. (The definition is extended to include the principle of improvement cutting.)

Improvement cutting.—Cutting in a forest beyond the sapling stage (second growth or old growth), the purpose of which is to bring the stand into better condition for silvicultural management, mainly through removing trees of undesirable form, condition, and species.

Liberation cutting.—Improvement cutting in which desirable understory trees are freed from suppression by removal of undesirable overstory trees which may be either old growth, second growth, or new growth.

Underplanting.—Setting out young trees, or sowing seed, under an existing stand.

MEASURES DESIGNED TO IMPROVE OLD-GROWTH STANDS

(Table 3)

IMPROVEMENT CUTTINGS

Improving the quality of old-growth stands presents the most difficult problem in the application of silviculture within the southern Appalachians.

Improvement cuttings, although designed particularly for the betterment of the larger diameter classes in the stand, in practice may also enable advance reproduction to develop and occasionally may even bring about the establishment of new reproduction. The correct application of improvement cutting depends largely upon the operator's ability to make such a selection of individual trees for cutting as will insure maximum productivity of the available growing stock. The actual procedure to be followed in an improvement cutting depends upon the nature of the individual stand. The general practice consists in girdling or felling the poorer trees that are competing with sound, thrifty, and otherwise desirable individuals.

Costs of improvement cuttings, and likewise of liberation cuttings and thinnings, vary widely, the variation depending upon whether

[14] SOCIETY OF AMERICAN FORESTERS, COMMITTEE ON TERMINOLOGY. FOREST TERMINOLOGY. Jour. Forestry 15: 68–101. 1917.

trees are cut and worked up into fuel wood or are merely girdled.[15] Except where the felling of undesirable trees is specifically indicated, as at points of special scenic value or extreme fire danger or where utilization is feasible, girdling is generally preferable to felling. Girdling is much cheaper for trees 8 inches or larger in breast-height diameter, and probably also for trees as small as 6 inches. Also, the branches and stems of standing dead trees decay gradually and in falling are less likely to break crop trees than are trees felled by cutting. Data are given in table 2 as to the labor required for girdling in comparison with that required for felling.

TABLE 2.—*Comparative labor requirements of girdling and felling hardwoods in cuttings for stand improvement*[1]

Average diameter at breast height (inches)	Trees removed per acre	Labor required per acre		Average diameter at breast height (inches)	Trees removed per acre	Labor required per acre	
		Girdling	Felling			Girdling	Felling
	Number	*Man-hours*	*Man-hours*		*Number*	*Man-hours*	*Man-hours*
18	5	0.3–0.7	0.7–1.2	8	10	0.30–0.5	0.60–0.85
	25	1.5–3.0	3.5–5.0		25	.75–1.5	1.75–2.50
	50	3.5–5.0	6.5–9.0		50	1.50–3.0	3.40–4.50
	75	5.0–7.0	9.5–12.0		100	3.50–5.5	7.00–9.00
	100	7.0–9.0	13.0–16.0		150	6.00–7.5	10.00–12.00
12	5	.25–.4	.5–.7		200	7.50–9.0	14.00–16.00
	25	.75–2.5	2.0–4.0				
	50	3.0–4.5	4.0–6.0				
	75	4.5–6.0	6.0–9.0				
	100	6.0–8.0	9.0–12.0				

[1] Figures are based on meager data.

In girdling, the tree should be chipped to a depth of from 1 to 2 inches, according to its size, and to a width of from 2 to 6 inches. The cambium should be completely severed, and no bark folds should be left.

In general, trees 5 inches or less in diameter should be felled; in addition, hollow and badly leaning trees that would be so weakened by girdling as to fall relatively soon should be felled rather than girdled. When trees are felled care should, of course, be taken to prevent breakage of crop trees, and all trees cut should be pulled down so that they lie on the ground.

Special care should be taken to safeguard survey-corner and bearing trees from either cutting or girdling.

A wide-spread condition calling for improvement cutting is described in table 3 as condition class 4. Here the dominant canopy contains a high proportion of inferior trees and the understory contains a poor stocking of desirables in severe competition with many undesirables (fig. 3). This is one of the most difficult stand conditions to treat, because of the inadequacy of the growing stock.

[15] In connection with stand-improvement work every effort should be made toward utilization of merchantable dead material present on the areas treated and of trees girdled or felled in the course of the work. In the mountain region, particularly, large quantities of dead chestnut will be found. The Forest Products Laboratory lists as follows the uses for which blight-killed chestnut is suitable, according to length of time dead and average condition of wood when cut: Up to 2 years (sapwood and heartwood sound), poles and mine timbers, highway and railway fence posts, and railroad ties; 2 to 4 years (sapwood decayed but heartwood sound and unchecked), boxes and crates, core stock, slack cooperage, yard lumber and planing-mill products, millwork, furniture and cabinetwork, coffins and caskets, and woodenware novelties; 4 to 6 years (sapwood decayed and heartwood checked but sound), rough construction, farm fence posts, tannin wood, and pulpwood; 6 years or more (heartwood badly checked and infected with decay), fuel wood.

The best that can be done is to favor thrifty overstory trees of desirable species by an improvement cutting and to encourage such desirable reproduction as exists under openings thus produced by a cleaning operation in the understory. (See heavy treatment for condition class 4, table 3.)

FIGURE 3.—Old-growth oak-chestnut stand containing many undesirable trees in the overstory. The understory contains but few desirable trees, which are in competition with many undesirables such as sourwood and dogwood. Needed treatment consists in an improvement cutting to favor the best individuals in the overstory and a cleaning to release understory trees in the openings produced by the improvement cutting.

Old-growth stands, particularly those occurring in coves or in the northern hardwood type, are occasionally of very good quality, the overstory containing a high proportion of good trees (fig. 4, *A*). Such a forest represents the final objective of silviculture, although in existing cases the end result has been a matter of accident rather than design (condition class 1, table 3). If such stands are to be har-

vested in the near future, no treatment is necessary. If, owing to inaccessibility or other economic reasons, they are to remain for more than 10 or 15 years, an improvement cutting to remove unmerchant-

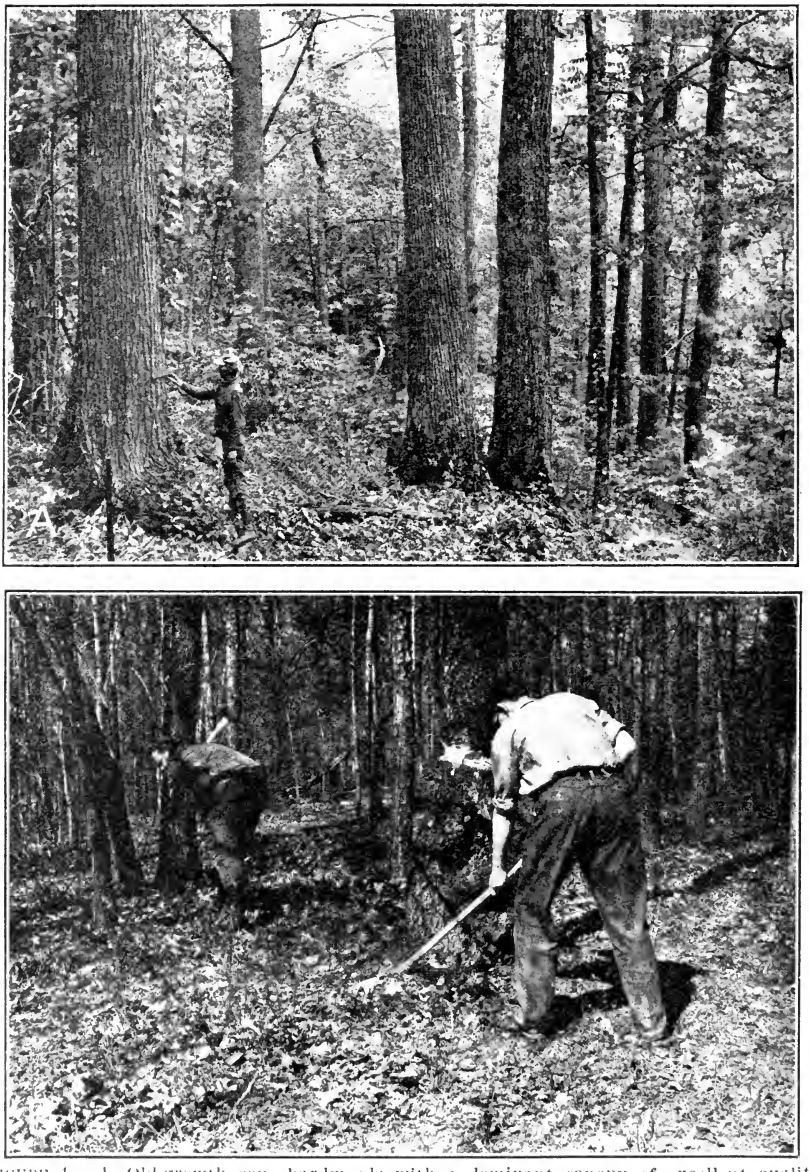


FIGURE 4.—*A*, Old-growth cove hardwoods with a dominant canopy of excellent quality (condition class 1, table 3). If such a stand is to be cut soon no treatment is necessary. If cutting is to be delayed beyond 10 years, unmerchantable trees should be cut or girdled to make way for the development of reproduction. *B*, The defective black oak has been girdled, and the axman is girdling a dogwood with a wide-spreading crown. The leaf litter is being removed, and the soil will be cut up with fire tools.

able overstory trees is recommended. This will help to maintain the waning vigor of the desirable overstory and will allow for the development of reproduction.

LIBERATION CUTTINGS

A not uncommon stand condition is that in which a decadent or highly defective overstory of old growth is suppressing an understory of desirable reproduction. If this desirable understory is relatively free of severe competition from inferior species in the understory (condition class 3), a liberation cutting alone is sufficient. If the desirable understory is in severe competition with inferior undergrowth (condition class 2, table 3), a cleaning should be combined with the liberation cutting.

The combination of a liberation cutting with a cleaning is particularly applicable on logged lands where stands of new growth free of overstory shading (condition classes 14–17, table 5) are intermingled with stands in which new growth occurs as an understory shaded by the residual defective overstory (condition classes 2–5, table 3).

EXAMPLE OF CLEANING COMBINED WITH LIBERATION CUTTING

Following a timber sale in 1929 on Bee Branch of Little Buck Creek, Pisgah National Forest, N. C., a combined liberation cutting and cleaning operation was carried out on 73 acres during the summer of 1931. Before the sale the stand had averaged about 5,000 board feet per acre in age classes ranging from 20 to 120 years, the bulk of the timber being in the oldest age class. There had been no recent fire over the area, and satisfactory reproduction was present over much of it. The timber sale removed material down to a breast-height diameter limit varying with species from 10 inches to 16 inches. All chestnut was designated for cutting.

After the sale there was present on the area an average of 800 board feet per acre, about 30 percent of which was in yellow poplar and red oak seed trees. Occasional large unmerchantable hickories, and large black gums, sweet birches, and red maples were left scattered over the area, along with defective trees of merchantable species.

In the liberation cutting, which was confined to coves and lower slopes, these undesirable holdovers and also the taller pole-sized trees of undesirable species were girdled or felled. Heavy cleanings were made wherever undesirable vegetation was crowding desirable reproduction. In the liberation cutting, 92 trees 3 inches and larger in diameter at breast height were girdled or felled per acre, and in the cleaning 171 stems per acre were cut. The combined operations required 7 man-hours per acre. The area was left completely stocked with good reproduction free to grow.

The crew included a regular warden as foreman and 4 or 5 axmen. The district ranger worked with the crew for the first half day to instruct them. The area was covered by narrow strips following the contours. The foreman worked in the center of this strip, for ease in supervising the cutters. He acted as an axman himself except when advising the others. The liberation and cleaning were done in one trip over the area.

BETTERMENT BY REPLACEMENT

In old-growth (and in second-growth) stands with a highly defective overstory, if the understory is absent or is made up of undesirable reproduction, measures for stand betterment must be

directed toward the replacement of the present stand by new reproduction.

Stands containing light-seeded species afford an unusual opportunity for such improvement. These stands occur commonly in the white pine-hardwood, yellow pine-hardwood, and cove-hardwood forests. Many of the light-seeded species grow rapidly and produce wood of good quality. In many instances the light-seeded species such as white pine, yellow poplar, and the yellow pines have been culled out, so that they are less fully represented now than formerly. Treatment should be designed not only to improve the composition and growth rate of the existing stand but to increase the proportion of the light-seeded species in the mixture. Conditions favoring natural reproduction of these species can be produced by exposing and scarifying the mineral soil on small spots and girdling the overstory above the spots. This work should be performed in late summer, before seed fall.

Figure 4, *B*, illustrates one method recommended for this operation. Each crew consists of 4 men, 1 man with an ax to choose and girdle large, defective overstory trees and such smaller inferior understory trees as may be heavily shading areas on which reproduction is to be induced, and 3 men using Rich or Council fire rakes to follow the axman, rake the litter and small vegetation from the areas overtopped by the crown spread of the girdled trees, and chop up the exposed soil. The leaf litter raked back should not be allowed to lie around the edge of the spot in windrows but should be scattered back 6 or 8 feet from the treated area. This reduces the chances of the area being covered again by wind-blown leaves. An hour's work by such a 4-man crew is sufficient to prepare 3 or 4 spots averaging 25 to 35 feet in diameter. Six to eight such spots per acre constitute a light treatment and 12 to 16 a heavy treatment. The diameter of the opening in the crown canopy should not be less than 25 or 30 feet. Smaller openings close too quickly, with the result that any reproduction established is prevented from occupying a dominant place in the crown canopy.

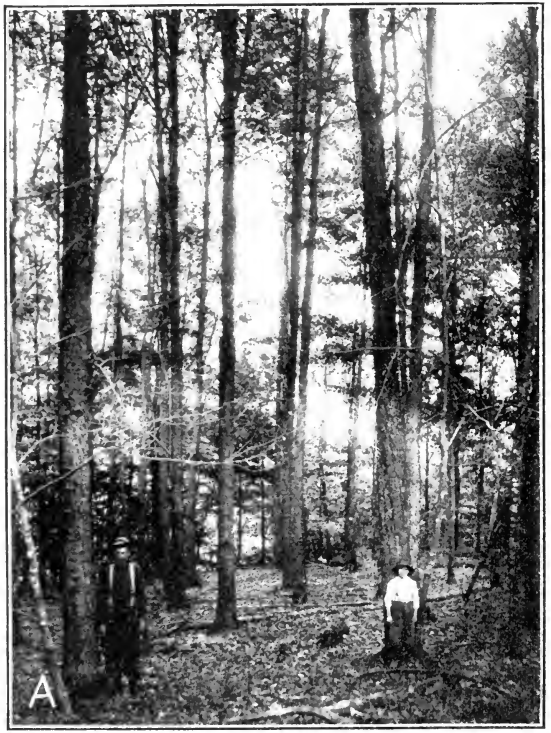
In tables 3 and 4 a footnote indicates condition classes in which soil-scarification methods should be considered if the stand contains seed trees of desirable light-seeded species.

Heavy seeds such as nuts and acorns are not so capable of wide dispersal as are the light seeds of such species as pines, ashes, and yellow poplar. As a rule heavy seeds require a covering of leaf litter for satisfactory germination and early survival. In stands containing only heavy-seeded species, the replacement of undesirable trees with new reproduction depends largely upon (1) maintaining a greater number of seed trees than would be necessary in the case of light-seeded species, (2) maintaining a layer of leaf litter on the ground, and (3) removing undesirable understory vegetation that would interfere with the development of new reproduction. Replacement may be expedited by actually planting seed or seedlings in openings large enough to insure that the young trees will be free from interference by large or small vegetation. For this purpose it is best to use species that are at least moderately tolerant of shade. (See list of species grouped according to tolerance, in the appendix.)

TABLE 3.—*Stand-improvement measures*[1] *for old-growth stands*[2] *forming either a continuous or a broken overstory*[3]

Stand conditions			Condition class	Suggested treatment	
				Light	Heavy
Dominant canopy good (75–100 percent desirable trees).	Stocking and condition of understory not important to improvement of stand at present time.		1	Improvement and liberation (advised only if logging is to be deferred beyond next decade): Girdle or cut worst of undesirables in overstory, to release desirable second growth or reproduction or provide for new reproduction.	Improvement and liberation (advised only if logging is to be deferred beyond next decade): Girdle or cut all of undesirables in overstory, to release desirable second growth or reproduction or provide for new reproduction.
Dominant canopy poor (0–74 percent desirable trees).	Good stocking of desirables in understory.	Competition of undesirables in understory severe.	2	Liberation: Girdle or cut especially wide-spreading undesirables in overstory that are overtopping best of desirables in understory. Improvement: In openings produced by liberation, girdle or cut undesirables of pole size that overtop or crowd best of desirables of pole size. Cleaning: In openings produced by liberation, cut enough undesirables in understory to release best desirables.	Liberation: Girdle or cut all of undesirable overstory. Improvement: In openings produced by liberation, girdle or cut all undesirables of pole size. Cleaning: In openings produced by liberation, cut all undesirables in understory that are competing with desirables.
		Competition of undesirables in understory not severe.	3	Liberation: Girdle or cut especially wide-spreading undesirables that are overtopping desirables in understory.[4]	Liberation: Girdle or cut all undesirables in overstory. Cleaning: Cut all competing undesirables in understory.[4]
	Poor stocking of desirables in understory.	Competition of undesirables in understory severe.	4	Light treatment inadequate.	Improvement: Girdle or cut undesirables in overstory. Cleaning: Girdle or cut undesirables in understory to favor desirables, if any are present. Spot clearing in understory, with supplementary planting. Later, release cuttings probably necessary.[4]
		Competition of undesirables in understory not severe.	5	Improvement: Girdle or cut wide-spreading undesirables in overstory, particularly those of light-seeded inferior species.[4]	Improvement: Girdle or cut all undesirables in overstory.[3]

[1] Applicable to sites I–III, inclusive (see pp. 11–12), in all forest types except spruce.
[2] Stands of trees 15 inches or more in diameter at breast height.
[3] For treatment of second-growth or new-growth stands occupying openings of more than one-fourth acre in broken old-growth canopy, see tables 4 and 5.
[4] Where seed-bearing trees of desirable light-seeded species are present in the overstory, soil scarification under the girdled trees or in openings left by cutting is suggested. (See pp. 23–23.)



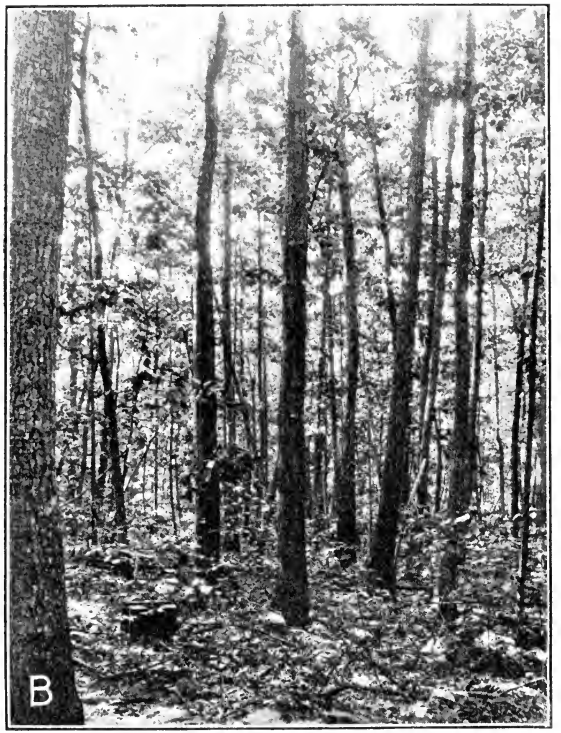


FIGURE 5.—*A*, Second-growth black cherry in the northern hardwood type on the Monongahela National Forest, W. Va. The dominant canopy is good. A few increment borings are necessary to determine whether density of stocking is slowing the growth rate appreciably. If so, the stand may be classified as condition class 6, and a thinning to favor the best trees is advisable. If the growth rate is well maintained, the condition class is 7 and no improvement measures are necessary. *B*, Thrifty second-growth stand of mixed oaks containing a high proportion of desirable trees in the dominant canopy (condition class 6), near Wardensville, W. Va. In stands such as are shown here and in *A* the understory is of minor importance. The treatment needed is a thinning to give the best dominant trees full opportunity for growth.

MEASURES DESIGNED TO IMPROVE SECOND-GROWTH STANDS

(Table 4)

THINNINGS TO IMPROVE THE GROWTH RATE AND COMPOSITION OF DENSELY STOCKED STANDS

Ordinarily, stands for which thinnings are recommended are overstocked stands, containing a high proportion of desirables in the dominant canopy (condition class 6, table 4) (fig. 5). If a series of thinnings at 5- or 10-year intervals is contemplated the rule is to thin lightly, removing the weaker trees, the defectives, some of the trees of less desirable species, and only enough of the dominant and codominant trees of good species to insure that the crown development (upon which depends the diameter growth) of those left will be unimpeded during the period before the next thinning.

When an early second thinning is not contemplated, the thinning should be heavier than this. The method recommended is to reserve from 50 to 75 crop trees[16] per acre in light treatment, from 75 to 125 per acre in more intensive treatment, and perhaps 150 to 250 per acre in treating dense second growth such as some old-field stands of the yellow pines, white pine, or yellow poplar. Immediately around these crop trees the stand should be thinned rather heavily, so that surrounding crowns will not close in on and interfere with the development of the crop trees for many years to come. Where widespreading, defective trees are removed, large openings cannot, of course, be avoided; it is to be expected that such openings will later be partly filled by reproduction.

EXAMPLE OF THINNING

An experimental thinning was made in a 40-year-old stand of yellow poplar near Cranberry, N. C. The stand contained 428 trees per acre, of which 238 were yellow poplars ranging up to 20 inches in diameter and up to 90 feet in height. Of the best dominant and codominant poplars, 84 per acre were selected as crop trees to be released from competition. The thinning removed 102 trees per acre, ranging from 6 to 21 inches in diameter at breast height. Of these, 88 were yellow poplars. The released trees were left free to grow for a long time before their crowns once more became crowded. Such operations correspond to the heavy treatment suggested for condition class 6 (table 4).

LIBERATION AND IMPROVEMENT CUTTINGS IN OVERSTORY, COMBINED WITH CLEANINGS IN UNDERSTORY

The overstory of second-growth stands in the southern Appalachians commonly contains a high proportion of trees of undesirable species and of inferior trees of good species. An understory of desirable reproduction is frequently present, which if released by the removal of poor overstory trees would subsequently take a place in the overstory. Such a transition would greatly improve the composition of the stand (condition classes 8 and 9, table 4).

[16] Trees reserved to be harvested when mature.

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TABLE 4.—*Stand-improvement measures* [1] *for second-growth stands* [2] *forming either a continuous or a broken canopy,* [3] *free of old-growth overstory*

Stand conditions			Condition class	Suggested treatment	
				Light	Heavy
Dominant canopy good (60–100 percent desirable trees).	Stocking and condition of understory not important to improvement of stand at present time.	Competition due to heavy stocking reducing growth rate of desirable overstory trees.	6	Thinning: Completely release 50 to 75 of best dominants per acre.	Thinning: Completely release 75 to 125 of best dominants per acre.
		Little if any unfavorable competition.	7	No treatment needed.	No treatment needed.
Dominant canopy poor (0–59 percent desirable trees).	Good stocking of desirables in understory.	Competition of undesirables in understory severe.	8	Liberation: Girdle or cut wide-spreading undesirables in overstory. Cleaning: In openings produced by liberation, cut undesirables in understory competing with best desirables.	Liberation: Girdle or cut all undesirables in overstory. Cleaning: In openings produced by liberation, cut undesirables in understory competing with desirables.
		Competition of undesirables in understory not severe.	9	Liberation: Girdle or cut wide-spreading undesirables in overstory that are overtopping desirables in understory.[4]	Liberation: Girdle or cut all undesirables in overstory.[4]
	Poor stocking of desirables in understory.	Competition of undesirables in understory severe.	10	Light treatment inadequate.	Improvement: Girdle or cut all undesirables in overstory. Cleaning: Girdle or cut undesirables in understory to favor desirables, if any are present. Under openings in overstory clear spots 10 to 12 feet in diameter and plant. (This method is particularly applicable to sites favoring fast growers such as white pine and yellow poplar.) [4]
		Competition of undesirables in understory not severe.	11	Improvement: Girdle or cut widespreading undesirables in overstory, particularly those of light-seeded inferior species.[4]	Improvement: Girdle or cut all undesirables in overstory. Supplementary planting under openings thus produced.[4]

[1] Applicable to sites I–III, inclusive (see pp. 11–12), in all forest types except spruce.
[2] Stands of poles 4.5 to 14 inches in diameter at breast height.
[3] For treatment of new-growth stands occupying openings of more than one-tenth acre in broken second growth, see table 5.
[4] Where seed-bearing trees of desirable light-seeded species are present in the overstory, soil scarification under the girdled trees or in openings left by cutting is suggested (pp. 23–24).

In liberation cuttings good judgment is required on the part of the operator selecting trees for removal. If the development of the desirable understory reproduction is jeopardized by severe competition from undesirables in the understory (condition class 8, table 4), a cleaning under the openings produced by the liberation cutting is necessary. In the cleaning operation the tops of trees 3 inches or less in diameter should be lopped off or should be partially cut and bent over. The lopping or bending point should be fully 2 or 3 feet below the tops of the crowns of the better trees left, so that the latter will be enabled to keep ahead of the sprouts of the trees cut and eventually shade them out. Trees more than 3 inches in diameter should be girdled or cut. Girdling is cheaper than cutting for the larger trees, and tends to reduce sprouting.

The cost of liberation cutting depends upon the methods used to dispose of the trees, the number of trees disposed of per acre, their sizes, and the brush and slash conditions on the area. Table 2 indicates the relation between diameter and labor requirements of girdling and felling.

In second-growth stands, liberation cuttings are not strongly differentiated from improvement cuttings. In the case of a poor overstory with desirable reproduction beneath, an improvement cutting fulfills the purpose of a liberation cutting. In some stands the overstory is so worthless that the future value of the stand depends absolutely upon replacement of the overstory by trees of good species and good form, wherever possible. In such a case the distribution of desirable reproduction in the understory determines what portions of the overstory are to be removed and the cutting is a true liberation. On the other hand, an overstory may be classified as poor but still contain a sufficient number of desirable trees to form a light stand. In such a case the cutting is principally for the purpose of improving the growing conditions of the good overstory trees and is a true improvement cutting, although it may release some desirable reproduction and thus serve as a liberation cutting also.

EXAMPLE OF LIBERATION CUTTING IN SECOND GROWTH

In the fall of 1931 an experimental liberation cutting was made on 2⅓ acres of the Mulky Creek watershed on the Cherokee National Forest, Ga. An overstory of inferior second-growth hardwoods was shading a good stand of white pine reproduction averaging 2,500 stems per acre, ranging from 1-year seedlings to 15-year-old saplings. The cutting removed an average of 153 hardwoods per acre. These ranged from 4 to 20 inches in diameter at breast height, averaging 6 or 7 inches. About half the number were girdled by chopping out a ring of chips 2 inches wide about 2½ feet above the ground. The remainder were girdled and poisoned with a special tool that makes it possible to perform both operations at the same time. Costs averaged slightly less for the latter method. This operation, in which skilled labor was used, required about 4 man-hours per acre. An examination made at the end of the first growing season following the treatment showed that the poisoned trees had fewer and smaller sprouts than those that had been girdled but not poisoned. Trees that had been girdled were dying rapidly, regardless of whether they had been poisoned.

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MEASURES DESIGNED TO IMPROVE NEW-GROWTH STANDS

(Table 5)

CLEANINGS TO IMPROVE THE GROWTH RATE AND COMPOSITION OF DENSELY STOCKED STANDS

Occasionally a dense growth of desirable reproduction becomes established after heavy logging. As the stand grows older, severe competition due to the density of stocking may reduce the growth rate of even the dominant trees. More commonly, the dense stand of tree sprouts and seedlings, shrubs, and vines that develops after cutting consists mainly of undesirable species. Usually enough good trees of the better species are scattered through this growth to stock the area if they are not crowded out or shaded out by undesirable trees or shrubs. Both these conditions are included in condition class 12, outlined in table 5. Cleanings in young stands such as those just described usually constitute the most valuable treatment that can be applied during the entire life of the stand.

In cleanings it is frequently necessary to choose crop trees from sprout clumps of desirable species. If possible sprouts should not be selected as crop trees unless they originate from stumps less than 2 inches in diameter. If it is necessary to use sprouts from stumps larger than 2 inches in diameter, those sprouts arising lowest on the stump, preferably at the root collar, should be selected. Decay transmission from a stump to a new sprout is less likely when the sprout arises at or near the ground. Of the others, only those need be removed that are impeding the growth of the crop tree or appear likely to do so. Where two sprouts are joined at the base, if one is cut butt rot is very likely to develop in the other. The danger is not very great if the cut sprout is so small (3 inches or less in breast-height diameter) that the wound will heal quickly. In the case of twin sprouts larger than this, either both stems should be left or both should be cut.[17]

A good method of removing sprouts around a sprout chosen as a crop tree is to sever them just below the crown. This restricts subsequent sprouting to a minimum and reduces danger of decay entering the crop tree from the point of cutting.

Where vines are injuring desirable young tree growth they should be severed. Complete protection from vines would of course mean not only one cutting but repeated returns to cut back the sprouts; a single treatment, however, if complete, is very beneficial.

Where shrubs, herbaceous vegetation, or vines are found competing with desirable tree seedlings in the understory, the condition falls within condition class 14, and cutting away the undesirable vegetation constitutes a cleaning in the understory such as is referred to in table 5.

Ability to recognize tree species during their early stages is essential to good cleanings, especially in species mixtures so complex as those found in the southern Appalachians. In addition, a knowledge of the characteristics of the individual species and the relative desirability of the species from the silvical and economic standpoints is necessary.

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[17] Decay factors in sprout thinning are discussed at greater length in the following publication: HEPTING, G. H. EASTERN FOREST TREE DISEASES IN RELATION TO STAND IMPROVEMENT. Emergency Conserv. Work Forestry Pub. 2: 4–5. 1933.

In cleaning, no more trees should be cut than are necessary to free the desired trees from competition. Where the less desirable individuals are not actually overtopping the desirable trees or severely restricting the lateral development of the crowns of desirables, they should be left as trainers for the latter and to keep the ground covered. Most of them will be shaded out later by the better trees. The density of the stand that should be left depends upon site quality and upon the percentage of good trees in the stand. For well-established reproduction of desirable species, satisfactory stocking has been set at one good tree to every 15-foot square, or about 200 trees per acre.

This standard of stocking is not advanced as one that can be realized on the average cut-over area in the southern Appalachian region. Studies by the Appalachian Forest Experiment Station [18] of unburned second-growth areas in the region have shown an average stocking of desirables much below this standard. Neither do the recommendations made in this publication mean that on an area where the stocking of desirables is below this standard all trees of undesirable species should be removed. In such a case sound, well-formed, and well-spaced trees of intermediate or even of poor species should be left in such numbers as to make the density of stocking approximate that of the standard.

If the trees to be released are several feet high the competing vegetation can be lopped off below the level of the tops of these trees. Instead of being completely severed it can be partly cut and then bent over. Sprouts from trees eliminated by the latter method tend to be less vigorous.

The machete is useful for cutting trees or shrubs 1½ inches or less in diameter, and the brush hook for stems up to 3 inches in diameter. For larger trees the ax should be used.

The cost of cleanings varies greatly with the condition of the stands treated and with the thoroughness and efficiency of the work.

LIBERATION OF DESIRABLE UNDERSTORY OVERTOPPED BY UNDESIRABLE NEW GROWTH

Another condition common in young stands is described in table 5 as condition class 15. Here an overstory of undesirable new growth (frequently sprouts) is overtopping an understory of desirable seedlings. A liberation cutting removing the inferior overstory is essential to stand improvement.

Instances in which desirable tree reproduction occurs as an understory to rhododendron and laurel thickets fall within condition class 15. If the reproduction is released by cutting it is likely to be subjected anew to competition by laurel or rhododendron sprouts from the cut stumps. Often the latter are too far away from the trees to menace them, however, owing to the fact that both laurel and rhododendron commonly grow in wide-spreading clumps the bases of which are separated by a space of 5 or 10 feet or more. Where suppressed tree seedlings are found among rhododendron and laurel they can sometimes be released by cutting or lopping back only those parts of the clumps that are nearest them.

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[18] FROTHINGHAM, E. H. TIMBER GROWING AND LOGGING PRACTICE IN THE SOUTHERN APPALACHIAN REGION. (Introduction by R. Y. Stuart.) U. S. Dept. Agr. Tech. Bull. 250, 93 pp., illus. 1931.

FIGURE 6.—*A*, Dense thicket of new growth after a burn on a clear-cut cove-hardwood area on the Pisgah National Forest, N. C. Poor dominant canopy of silverbell, sumac, and chestnut sprouts 10 to 25 feet high, suppressing a desirable understory of yellow poplar 2 to 3 feet high. The same stand as affected by a cleaning operation is shown in *B* and in figure 7. *B*, Stand shown in *A* after cleaning operation removed silverbell and chestnut sprouts. The thin-crowned sumac was not considered a serious competitor, and much of it was left standing.

EXAMPLE OF LIBERATION CUTTING IN NEW GROWTH

Near Lookingglass Rock, Transylvania County, N. C., a heavy stand of reproduction of yellow poplar and other desirable species appeared after a severe burn in 1916, but was soon overtopped by a dense cover of sumac, chestnut, and silverbell. In 1924 this undesirable cover was 10 to 25 feet high, and the yellow poplars were

FIGURE 7.—Stand shown in figure 6, 4 years after the cleaning operation. The cleaning resulted in definite establishment of the desirable yellow poplar.

only 2 or 3 feet high. In that year the chestnut, the silverbell, and some of the sumac were cut on sample plots (fig. 6), other plots being left untreated. In 1933 there were 190 unsuppressed yellow poplar trees per acre on the treated plots (fig. 7) but only 93 per acre on the untreated plots.

TABLE 5.—*Stand-improvement measures* [1] *for new-growth stands* [2] *on areas of more than one-tenth acre free of old-growth or second-growth canopy*

Stand conditions			Condition class	Suggested treatment	
				Light	Heavy
Dominant canopy good (60–100 percent desirable trees).	Condition and stocking of understory not important to improvement of stand at present time.	Competition due to heavy stocking reducing growth rate of desirable overstory trees.	12	Cleaning: Completely release 50 to 100 of best desirables per acre.	Cleaning: Completely release 100 to 150 of best desirables per acre.
		Little if any unfavorable competition.	13	No treatment needed	No treatment needed.
Dominant canopy poor (0–59 percent desirable trees).	Good stocking of desirables in understory.	Competition of undesirables in understory severe.	14	Liberation: Cut undesirables in dominant canopy to free desirable understory trees. Cleaning: Competely release 50 to 100 of the best trees per acre.	Liberation: Cut undesirables in dominant canopy to free desirable understory trees. Cleaning: Completely release 100 to 150 of the best trees per acre.
		Competition of undesirables in understory not severe.	15	Liberation: Cut undesirables in dominant canopy to free desirable understory trees. Cleaning: Completely release 50 to 100 of the best trees per acre.	Liberation: Cut undesirables in dominant canopy to free desirable understory trees. Cleaning: Completely release 100 to 150 of the best trees per acre.
	Poor stocking of desirables in understory.	Competition of undesirables in understory severe.	16	Light treatment inadequate	Cleaning, combined with clearing in spots and planting. Subsequent cleaning of planted trees probably necessary.
		Competition of undesirables in understory not severe.	17	Liberation: Cut worst of undesirables in overstory. Cleaning: Completely release 50 to 100 of the best trees per acre.	Liberation: Cut all undesirables in overstory. Cleaning: Completely release 100 to 150 of the best trees per acre. Supplementary planting on cleared strips or spots suggested.

[1] Applicable to sites I–III, inclusive (pp. 11–12), in all forest types except spruce.
[2] Stands of reproduction up to 4.5 inches in diameter at breast height.

MEASURES DESIGNED TO ENCOURAGE GAME

Since the growing of desirable timber ordinarily takes precedence over game management, on the best sites at least, and some tree species valuable for game-food production are relatively poor for timber production, stand-improvement operations in general will unavoidably reduce the quantity of game food. An exception exists in that the cutting or girdling of trees of certain species, by giving rise to sprouts, will increase the quantity of browse available to deer. It should be kept in mind that to sacrifice 1 or 2 crop trees per acre on the better sites in favor of game-food trees, by leaving the former unreleased, will make very little difference in the final timber crop but may mean the difference between a critical and a satisfactory game-food situation. On the poorer sites, where game is likely to represent a larger part of an area's total productivity, greater sacrifices of this nature are justifiable. It should be remembered, also, that game-food species fulfill a valuable protective function in diverting birds and animals from the seed of species more valuable for timber.

Dogwood and black gum rank high as producers of food available to birds and animals during the fall and winter. Other species that produce food for game are hickory, holly, beech, chinquapin, persimmon, magnolia, and the oaks. For some game birds the smaller acorns, such as those of white, post, and black oak, are particularly desirable.

On many areas in the southern Appalachians, particularly areas well stocked with new growth, young stems of dogwood, black gum, hickory, and other game-food species are so numerous that after a cleaning operation the number of such trees left in untreated spaces between crop trees is sufficient to meet game-food needs. On areas not so well stocked, or where game-food species are scarce, it is advisable to favor 5 or 10 such trees per acre. Girdling of large hickory and black gum holdovers destroys one of the most abundant sources of game food. However, since such trees present one of the most serious silvicultural obstacles to the development of desirable new growth, not more than 1 or 2 of them should be left per acre. These should be so chosen as to overtop the minimum quantity of new growth. Occasional holdovers, owing to competition before cutting, have high crowns towering well above the new growth. Such trees are preferable for reservation as game-food trees, because they offer minimum competition to developing young stands. Three or four such trees standing close together do much less damage silviculturally than they would if isolated.

Small thickets of alder are fairly common in the southern Appalachians. These thickets usually occur along stream margins on land formerly cultivated, and seldom cover more than 1 or 2 acres. Frequently a scattering of desirable tree reproduction is intermingled with the alder but is handicapped by it. Such cover, although it adds but little to an area's timber production, forms a favorable winter habitat for grouse and woodcock. It is suggested that little or no cutting be done in such thickets. Rather commonly, also, individuals or groups of persimmon and haw occur on margins of old fields. These, likewise, should preferably be spared in silvicultural operations.

MEASURES TO PREVENT EROSION AND TO PROMOTE ABSORPTIVE SOIL CONDITIONS

In the southern Appalachian region forest cover plays an important part in the regulation of stream flow and the control of erosion. If well maintained and protected from fire, it reduces run-off and holds the soil firmly in place, thus tending to minimize floods and to stabilize low-water flow. It is primarily due to this fact that large areas have been purchased in the region for national-forest purposes. In many parts of the region precipitation exceeds 80 inches a year and slopes are steep; here it is highly important that rapid surface run-off at times of heavy rains be prevented.

In countries where flood-control activities have gone much further than in the United States, watershed-protection measures supplemental to continuous maintenance of a forest cover are in common practice.

One way to increase the absorption of water into the soil is to construct a series of ditches along the contours. Such ditches, by holding the water running off the surface, permit it to soak into the soil. The elevational difference between them should be determined more by steepness of slope and depth of soil than by rate of surface run-off. On steep slopes, and where the soil is thin, an elevational difference of 100 feet may not be too great. On gentle slopes where the soil is deep, the elevational interval between ditches may be 50 feet or less. Areas in sections where high surface run-off takes place during times of torrential rain need proportionally larger numbers of ditches per acre than areas in sections where surface run-off is normally light. The ditches on a given slope need not be continuous. In fact, a long ditch is less desirable than a series of short ones, because its outside embankment may fail and still worse run-off conditions result. As an extreme the ditches may take the form of a series of small pits or shallow holes scattered at random up and down the slope. When absorptive ditches are prepared in connection with stand-improvement work, the vegetative material cut should be placed in windrows below the ditch rather than above it.

Sooner or later the ditches fill with litter and detritus washed from the slopes above them. Most of this material is vegetable matter, the decomposition of which enriches the soil and adds to its water-absorptive capacity; consequently, instead of clearing out the old ditches it is advisable to prepare new ones.

Run-off from slopes subject to abnormal erosion can be diminished also by means of a system of brush fences approximately following the contours, such as is shown in figure 8, *A*. At the bottoms of such slopes, especially talus slopes, often it is desirable to use some form of cribbing that will catch and hold the larger rock fragments (fig. 8, *C*).

Another method of assisting water absorption, retarding surface run-off in time of heavy rains, and controlling erosion, is to construct check dams, a series of steps in the bed of a small stream (figs. 8, *B*, and 9). The function of check dams is to reduce the normal grade of the stream and thus reduce its velocity and silt-carrying capacity, to catch and hold debris, to increase water percolation, to

prevent channel cutting, and to promote tree and brush growth in the drainage channel.

Check dams need not be elaborately constructed. They can be built of logs, rock, and other material obtained locally.

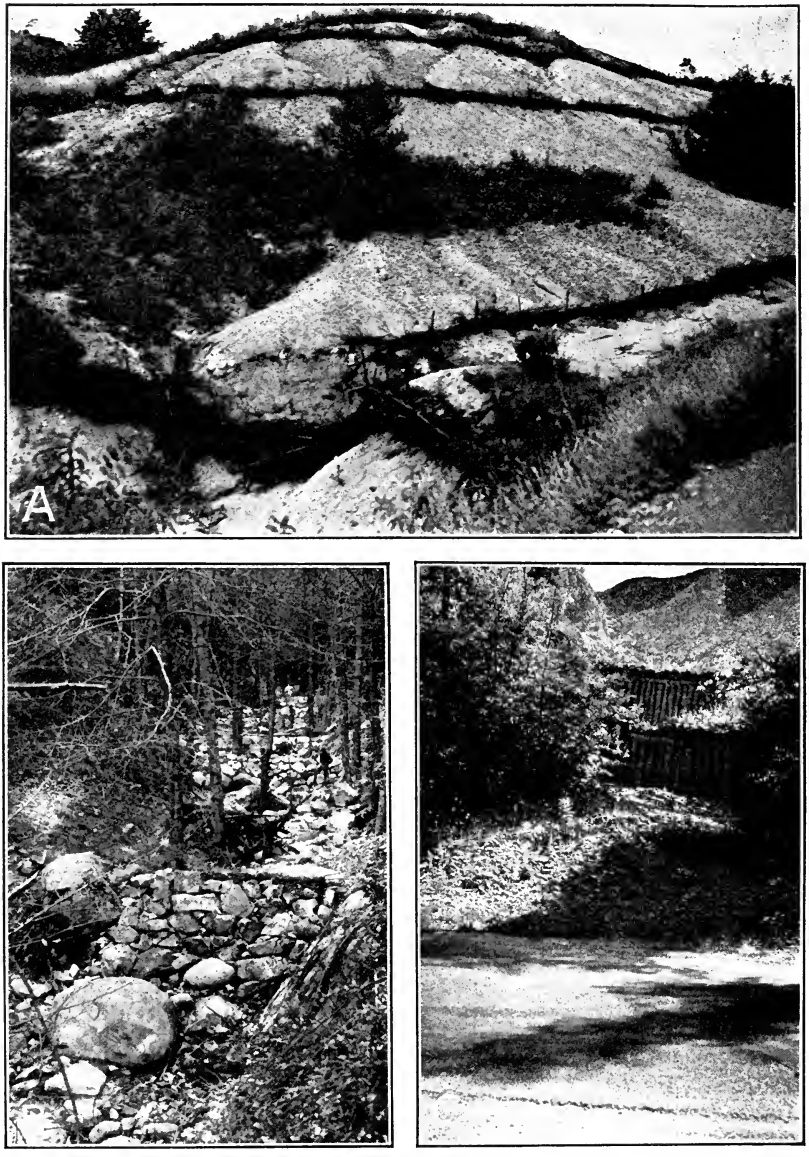

FIGURE 8.—*A*, Brush fencing on open slope to control erosion and aid in restoring cover. Such barriers should be supplemented with planting. *B*, Loose rock check dams in mountain stream. *C*, Log cribbing to catch rock fragments and other eroded material washed down from denuded hillside.

Check dams are subject to the same physical forces that affect larger dams, and should be constructed with due regard for hydraulic principles. This entails care to prevent cutting around the

abutments, to prevent undercutting at the foot of the dam, and to prevent internal stresses, set up by the combined flow through and over the dam, that may result in direct failure. The top of the dam should be lower in the middle than at the ends.

When the dams are made of rock, the stones should be so keyed together as to bind firmly and hold against pressure. Mere piles of loose small stones are inadequate to withstand large flows. Where the only stones available are small or cannot be made to fit tightly without the use of cement or some other binder, woven-wire fencing should be used to hold them together. Where the height of the dam need not be so much as 4 feet and the stream gradient is gentle, a dam of loose rock and wire is adequate. Where greater height is necessary, the stream gradient is steep, and maximum storage is desirable, the dam should be constructed of stone masonry.

FIGURE 9.—Check dams across a small gully. These were constructed entirely of local material. Such check dams help to prevent local floods and to prevent further scouring of gullies and washes.

The detention basins behind check dams fill quickly if there is much erosion above them. The filled-in basins soon support a stand of herbaceous vegetation. For lasting benefit, they should be planted with trees. Cuttings of willows and poplars are particularly satisfactory for such planting because they withstand sedimentation and thrive in moist soil. Deep-rooted species such as sycamore are to be preferred to such species as hemlock and beech.

For erosion-control plantings in active gullies black locust is particularly recommended, because of the rapid growth and wide spread of its roots. On open lands the yellow pines, either pure or in mixture with black locust, afford the best prospects of success. Trees planted on eroded lands should be set closer together than is usual in forest plantations, because of the great need of quickly establishing a full stand. For areas severely affected by erosion a spacing of

5 by 5 feet or even 4 by 4 feet is not too close. An irregular spacing is probably more effective in holding the soil than a regular one. Any shrubby or tree vegetation on severely eroded areas should be preserved, even though of species classed in general as undesirable.

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APPENDIX

SOUTHERN APPALACHIAN FOREST TYPES RECOGNIZED BY THE COMMITTEE ON FOREST TYPES, SOCIETY OF AMERICAN FORESTERS

For analysis of special silvicultural problems, a more detailed classification of tree species associations may be needed than the six major forest types described in this publication. Such a classification has been prepared by a committee of the Society of American Foresters.[19] The types of that classification included in the individual "major forest types" of the southern Appalachians outlined in this publication are as follows, the serial numbers being those used by the committee:

SPRUCE

5, pin cherry; 16, yellow birch-red spruce; 18, red spruce; 19, red spruce-southern balsam fir.

NORTHERN HARDWOODS

12, sugar maple-beech-yellow birch; 14, sugar maple; 15, yellow birch; 57, beech-sugar maple.

OAK-CHESTNUT

30, post oak; 31, post oak-blackjack oak; 32, black oak-post oak; 33, scarlet oak-black oak; 34, southern red oak-scarlet oak; 35, bear oak; 36, chestnut oak; 46, eastern red cedar; 50, white oak; 52, red oak; 56, chestnut.

COVE HARDWOODS

11, hemlock; 47, black locust; 50, white oak; 51, red oak-basswood-white ash; 53, yellow poplar; 54, yellow poplar-hemlock; 55, yellow poplar-white oak-red oak; 57, beech-sugar maple; 58, beech; 59, river birch-sycamore.

YELLOW PINE-HARDWOODS

37, pitch pine; 38, shortleaf pine; 39, shortleaf pine-post oak; 40, shortleaf pine-southern red oak-scarlet oak; 41, shortleaf pine-white oak; 42, shortleaf pine-Virginia pine; 43, Virginia pine-southern red oak; 44, Virginia pine.

WHITE PINE-HARDWOODS

/9, white pine; 10, white pine-hemlock; 48, white pine-chestnut oak-chestnut.

PRINCIPAL FOREST TREES NATIVE TO THE SOUTHERN APPALACHIANS

In this list boldface type indicates species of commercial importance in the region and asterisks indicate trees that commonly do not develop to saw-log size there. The nomenclature is that given in United States Department of Agriculture Miscellaneous Circular 92, Check List of the Forest Trees of the United States: Their Names and Ranges.

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[19] SOCIETY OF AMERICAN FORESTERS, COMMITTEE ON FOREST TYPES. FOREST COVER TYPES OF THE EASTERN UNITED STATES. Jour. Forestry 30: 451–498. 1932.

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Common name	*Scientific name*
Ash, Biltmore white	*Fraxinus biltmoreana.*
Ash, green	*Fraxinus pennsylvanica lanceolata.*
Ash, red	*Fraxinus pennsylvanica.*
Ash, white	*Fraxinus americana.*
Aspen	*Populus tremuloides.*
Aspen, largetooth	*Populus grandidentata.*
Basswood (6 species)	*Tilia* sp.
Beech	*Fagus grandifolia.*
*Beech, blue	*Carpinus caroliniana.*
Birch, river	*Betula nigra.*
Birch, sweet	*Betula lenta.*
Birch, yellow	*Betula lutea.*
Buckeye, Ohio	*Aesculus glabra.*
Buckeye, yellow	*Aesculus octandra.*
Butternut	*Juglans cinerea.*
Cedar, eastern red	*Juniperus virginiana.*
Cherry, black	*Prunus serotina.*
*Cherry, pin	*Prunus pennsylvanica.*
Chestnut	*Castanea dentata.*
Coffeetree	*Gymnocladus dioicus.*
Cottonwood, southern	*Populus deltoides virginiana.*
*Crab apple (7 species)	*Malus* sp.
***Dogwood**	*Cornus florida.*
Elm, American	*Ulmus americana.*
Elm, red	*Ulmus serotina.*
Elm, slippery	*Ulmus fulva.*
Elm, winged	*Ulmus alata.*
Fir, southern balsam	*Abies fraseri.*
Gum, black	*Nyssa sylvatica.*
Gum, red	*Liquidambar styraciflua.*
Hackberry	*Celtis occidentalis.*
*Hawthorn (22 species)	*Crataegus* sp.
Hemlock, Carolina	*Tsuga caroliniana.*
Hemlock, eastern	*Tsuga canadensis.*
Hickory	*Hicoria ovalis.*
Hickory, bitternut	*Hicoria cordiformis.*
Hickory, mockernut	*Hicoria alba.*
Hickory, pignut	*Hicoria glabra.*
Hickory, pignut	*Hicoria pallida.*
Hickory, shagbark	*Hicoria ovata.*
Hickory, bigleaf shagbark	*Hicoria laciniosa.*
Hickory, southern shagbark	*Hicoria carolinae-septentrionalis.*
*Holly	*Ilex opaca.*
*Hophornbeam	*Ostrya virginiana.*
Locust, black	*Robinia pseudoacacia.*
Locust, honey	*Gleditsia triacanthos.*
Magnolia, cucumber	*Magnolia acuminata.*
*Magnolia, mountain	*Magnolia fraseri.*
*Magnolia, umbrella	*Magnolia tripetala.*
Maple, black	*Acer nigrum.*
Maple, red	*Acer rubrum.*
Maple, silver	*Acer saccharinum.*
Maple, sugar	*Acer saccharum.*
*Mountain-ash	*Sorbus americana.*
*Mulberry, red	*Morus rubra.*
Oak, black	*Quercus velutina.*
*Oak, blackjack	*Quercus marilandica.*
Oak, chestnut	*Quercus montana.*
Oak, chinquapin	*Quercus muehlenbergii.*
Oak, pin	*Quercus palustris.*
Oak, post	*Quercus stellata.*
Oak, red	*Quercus borcalis.*
Oak, scarlet	*Quercus coccinea.*
Oak, shingle	*Quercus imbricaria.*
Oak, southern red	*Quercus rubra.*
Oak, swamp white	*Quercus bicolor.*

Common name	*Scientific name*
Oak, water	*Quercus nigra.*
Oak, white	*Quercus alba.*
Persimmon	*Diospyros virginiana.*
Pine, mountain	*Pinus pungens.*
Pine, northern white	*Pinus strobus.*
Pine, pitch	*Pinus rigida.*
Pine, shortleaf	*Pinus echinata.*
Pine, Virginia	*Pinus virginiana.*
Poplar, Balm-of-Gilead	*Populus balsamifera candicans.*
Poplar, yellow	*Liriodendron tulipifera.*
*Redbud	*Cercis canadensis.*
*Sassafras	*Sassafras variifolium.*
*Serviceberry	*Amelanchier canadensis.*
*Silverbell	*Halesia carolina.*
Silverbell, mountain	*Halesia monticola.*
*Sourwood	*Oxydendrum arborcum.*
Spruce, red	*Picea rubra.*
Sycamore	*Platanus occidentalis.*
Walnut, black	*Juglans nigra.*
Willow, black	*Salix nigra.*
*Yellowwood	*Cladrastis lutea.*

SHRUBS AND VINES COMMON IN THE SOUTHERN APPALACHIANS

In this list boldface type indicates species generally or locally abundant that sometimes interfere with reproduction of desirable tree species. Species confined to moist situations are indicated by the letter M. The list includes some species that sometimes reach small tree size. The nomenclature is that used in Standardized Plant Names, published in 1923 by the American Joint Committee on Horticultural Nomenclature.

Common name		*Scientific name*
Alder	(M)	*Alnus* sp.
Amorpha		*Amorpha* sp.
Azalea		*Azalea* sp.
Bittersweet, American		*Celastrus scandens.*
Blackberry		*Rubus* sp.
Bladdernut, American		*Staphylea trifolia.*
Blueberry		*Vaccinium* sp.
Buckthorn, Carolina		*Rhamnus caroliniana.*
Bush-honeysuckle		*Diervilla* sp.
Buttonbush, common	(M)	*Cephalanthus occidentalis.*
Chokeberry, black		*Aronia melanocarpa.*
Chinquapin		*Castanea pumila.*
Clethra	(M)	*Clethra* sp.
Currant		*Ribes* sp.
Devil's-walkingstick	(M)	*Aralia spinosa.*
Dogwood (shrubby species)		*Cornus* sp.
Dutchman's-pipe	(M)	*Aristolochia sipho.*
Elder	(M)	*Sambucus* sp.
Euonymus, brook	(M)	*Euonymus americanus.*
Fringetree, white	(M)	*Chionanthus virginica.*
Gooseberry		*Ribes* sp.
Grape		*Vitis* sp.
Greenbrier		*Smilax* sp.
Hazelnut		*Corylus* sp.
He-huckleberry		*Lyonia ligustrina.*
Holly (shrubby species)		*Ilex* sp.
Honeysuckle		*Lonicera* sp.
Hoptree		*Ptelea trifoliata.*
Huckleberry		*Gaylussacia* sp.
Hydrangea, smooth	(M)	*Hydrangea arborescens.*
Jersey-tea		*Ceanothus americanus.*
Leucothoe, drooping	(M)	*Leucothoe catesbaei.*
Locust (shrubby species)		*Robinia* sp.

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Common name		*Scientific name*
Menziesia, Allegheny		*Menziesia pilosa.*
Mockorange	(M)	*Philadelphus* sp.
Mountain andromeda	(M)	*Pieris floribunda.*
Mountain-laurel		*Kalmia latifolia.*
Mountain maple	(M)	*Acer spicatum.*
Oil-nut		*Pyrularia pubera.*
Papaw	(M)	*Asimina triloba.*
Raspberry		*Rubus* sp.
Rhododendron		*Rhododendron* sp.
Rose		*Rosa* sp.
Spicebush	(M)	*Benzoin aestivale.*
Spirea		*Spiraea* sp.
Striped maple	(M)	*Acer pennsylvanicum.*
Sumac		*Rhus* sp.
Sweetfern		*Comptonia asplenifolia.*
Sweetleaf, common		*Symplocos tinctoria.*
Sweetshrub, common		*Calycanthus floridus.*
Viburnum		*Viburnum* sp.
Virginia creeper		*Ampelopsis quinquefolia.*
Witch-hazel, common		*Hamamelis virginiana.*
Yellowroot	(M)	*Zanthorhiza apiifolia.*

TREE SPECIES COMMON IN THE SOUTHERN APPALACHIANS, GROUPED ACCORDING TO SHADE TOLERANCE

Tolerant	*Moderately tolerant*	*Intolerant*
Beech	Ashes	Aspens
Beech, blue	Basswoods	Birches
Buckeyes	Chestnut	Cedar, eastern red
Dogwood	Elms	Cherries
Fir, southern balsam	Gum, red	Locusts
Gum, black	Hickories	Oak, black
Hemlocks	Magnolias	Oak, red
Holly	Oak, chestnut	Oak, scarlet
Hophornbeam	Oak, post	Oak, southern red
Maples	Oak, white	Persimmon
Redbud	Pine, northern white	Pine, mountain
Serviceberry	Silverbell	Pine, pitch
Spruce, red	Sourwood	Pine, shortleaf
		Pine, Virginia
		Poplar, yellow
		Sassafras
		Sycamore
		Walnut
		Willow, black

IMPORTANT FOREST INSECTS OF THE SOUTHERN APPALACHIANS

Many species of insects attack the forest trees of the Appalachian region. Some of them are very destructive. The more important of these insects are listed here, in groups according to the type of damage they do.[20] (Information on damaging insects may be obtained from the Division of Forest Insects, Bureau of Entomology, Washington, D. C.)

TREE-KILLING BARK BEETLES

Southern pine beetle (*Dendroctonus frontalis* Zimm.).
Eastern spruce beetle (*Dendroctonus piceaperda* Hopk.).
Turpentine beetles (*Dendroctonus valens* Lec., *Dendroctonus terebrans* Oliv.).
Engraver beetles (*Ips* spp.).
Hickory bark beetle (*Scolytus quadrispinosus* Say).

[20] This list is adapted from the following publication: CRAIGHEAD, F. C., and MIDDLETON, W. AN ANNOTATED LIST OF THE IMPORTANT NORTH AMERICAN FOREST INSECTS. U. S. Dept. Agr. Misc. Pub. 74, 30 pp. 1930.

INSECTS BORING IN LIVING TREES

Small metallic wood and bark borers (*Agrilus anxius* Gory, *Agrilus bilineatus* Web.).
Locust borer (*Cyllene robiniae* Forst.).
Sugar maple borer (*Glycobius speciosus* Say).
Living hickory borer (*Goes pulcher* Hald.).
Living beech borer (*Goes pulverulenta* Hald.).
White oak borer (*Goes tigrina* DeGeer).
Oak sapling borer (*Goes tessellata* Hald.).
Eastern hemlock bark borer (*Melanophila fulvoguttata* Ham.).
Cottonwood borer (*Plectrodera scalator* Fab.).
Prionid root borers (*Prionus* spp.).
Red oak borer (*Romaleum rufulum* Hald.).
Elm borer (*Saperda tridentata* Oliv.).
Linden borer (*Saperda vestita* Say).
Poplar borer (*Saperda calcarata* Say).
Carpenter worm (*Prionoxystus robiniae* Peck).
Cambium miners (*Agromyza aeeris* Greene, *Agromyza amelanchieris* Greene).

INSECTS AFFECTING FOREST PRODUCTS

Ambrosia beetles or pinhole borers.
Columbian timber beetle (*Corthylus columbianus* Hopk.).
Oak timber worm (*Eupsalis minuta* Drury).
Sapwood timber worm (*Hylecoetus lugubris* Say).
Pine sawyers (*Monochamus* spp.).
Carpenter ant (*Camponotus herculeanus pennsylvanicus* DeG.).

INSECTS AFFECTING REPRODUCTION

Pales weevil (*Hylobius pales* Boh.).
Pine bark louse ((*Chermes*) *Pineus pinicorticis* Fitch).
May beetles or white grubs (*Phyllophaga* spp.).
White pine weevil (*Pissodes strobi* Peck).

DEFOLIATING INSECTS

Locust leaf miner (*Chalepus dorsalis* Thunb.).
Orange-striped oak worm (*Anisota senatoria* A. and S.).
Spiny oak worm (*Anisota stigma* Hbn.).
Green-striped maple worm (*Anisota rubicunda* Fab.).
Spruce bud worm (*Cacoecia fumiferana* Clem.).
Catalpa sphinx (*Ceratomia catalpae* Bdv.).
Brown-tail moth (*Nygmia phaeorrhoea* Donovan).
Oak and maple defoliators (*Heterocampa* spp.),
Tent caterpillars (*Malacosoma* spp.).
Gypsy moth (*Porthetria dispar* L.).

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